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Editorial

Build a Safer Cyberspace: In today's digital era, cybersecurity has become an essential pillar of personal, institutional, and national safety. With the rapid advancement of technology, nearly every aspect of human life - education, communication, business, and governance relies heavily on digital platforms. While this dependence brings great convenience, it also puts users to various cyber risks. Safeguarding information systems from unauthorized access, misuse, or damage is no longer a choice; it is a necessity to ensure the continuity and trustworthiness of digital operations. Robust cybersecurity measures are vital for ensuring national security, economic stability, and public trust in digital systems.

Unfortunately, as technology advances, so do the tactics of cybercriminals. Each year, millions of individuals fall victim to online scams, identity theft, and data breaches. Fraudulent emails, phishing messages, fake job offers, and cloned websites are meticulously cleverly designed to deceive unsuspecting users into revealing sensitive information. Cybercriminals often target social media sites, e-commerce sites, and online banking platforms. Even well-educated and tech-savvy individuals are deceived by sophisticated threats like ransomware and deepfake-based fraud. These scams not only cause significant financial losses but also erode confidence in digital services.

To combat these growing cyber threats requires proactive awareness and vigilance. The first step in cybersecurity is for people to adopt safe online practices, such as creating strong passwords, using two-factor authentication, avoiding suspicious links, and regularly updating software. Government agencies, educational institutions, and business organizations should conduct regular cybersecurity awareness programs and workshops to promote cyber safety. Implementing advanced security measures such as encryption, intrusion detection systems, and secure network protocols is essential to protect sensitive information. Greater awareness about the nature of cyber threats empowers users to prevent them effectively.

In the end, cybersecurity is about empowerment, rather than just safety. A secure digital environment fosters innovation, economic growth, and national development. When citizens view cybersecurity as a shared duty and act responsibly to safeguard their data, they help build a stronger, more resilient digital nation capable of thriving confidently in the cyber age.

Prevent, Protect, and Prosper in the Cyber Age

New Delhi **Editor**

30th September 2025

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Contents

Classification of Hyperspectral Images: A Case Study at Lonar

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ABSTRACT

The Remote sensing technology is useful at various applications, specially in the extraction of minerals identification, lithological discrimination and identifying soil and earth surface characteristics. The proposed works aims at classifying the Earth surface at Lonar crater using Hyperspectral remote sensing mineral mapping data is categorized into multispectral and hyperspectral data. Hyperspectral remote sensing offers spectral bands with high spectral resolutions delivering highest accuracy in classification

Various classification techniques have been developed for both data types. For multispectral data, techniques such as Principal Component Analysis, Independent Component Analysis and the Crosta technique are commonly used. For hyperspectral data, more advanced methods like Matched Filtering, Mixture Tuned Matched Filtering, Spectral Angle Mapper, and Spectral Feature Fitting are employed. This paper emphasizes hyperspectral data techniques due to their superior advantages and accuracy. The spectral classification using hyperspectral data gave accuracy of 87.21% using Spectral Angle Mapper Technique.

KEYWORDS *: Hyperspectral, Mineral mapping, Remote sensing, Spectral angle mapper, Spectral classification.*

INTRODUCTION

Remote sensing has emerged as a powerful tool in the field of Earth observation and it is having with various applications like Disaster analysis, surface monitoring, mineral mapping and lithological mapping. The, hyperspectral remote sensing and multispectral remote sensing is useful for mineral mapping. Hyperspectral images are having lots of spectral bads with higher spectral resolution as compared to multispectral images. The unique spectral signature obtained by using electromagnetic spectrum data is having significant role in spectral classification[1]. One of the most widely used sensors for hyperspectral imaging is the Hyperion sensor onboard NASA's EO-1 satellite. It is having 242 spectral bands covering the visible to shortwave infrared range. This paper focuses on the preprocessing and spectral classification of hyperspectral images obtained from the Hyperion sensor, aiming to improve the reliability and accuracy of mineral mapping.

Minerals are the natural resources having significance in the economy of any country. With the advent of technology, it is possible to analyze the earth surface and find out minerals available on the earth surface. Various minerals available can be identified and their potential applications can be explained with the help of remote sensing technology. Lonar Crater is having historic importance and formed in the deccan plateau of basaltic rocks. This crater has been studied for years through various geological, magnetic, electrical, geochemical, physical and structural analysis by number of researchers but it is not studied through remote sensing. Also, the Lonar Crater is important for studying its substantial features like its origin as volcanic eruption or meteorite burst, salinity of the Lonar lake water, mineralogical characterization and types of rocks at Crater. Hence the present work focuses on surface mineral mapping using remote sensing and GIS data for Lonar Crater as well as validating the results of various researchers, through remote sensing technology. This work will be the base for researchers in future for Lunar studies and for studying various craters available on the earth surface.

The number of researchers has worked on the different application using remotely sensed images, like ship detection[2][3] or any object detection, terrain and analysis[4], mineral mapping[5] and identification using multispectral and hyperspectral images. The Work done on the shores of Lake Salda shows the presence of minerals hydromagnesite, vermiculite, rivadavite and trona which were already identified by various researchers. Minerals tincalconite, ulexite and colemanite were also detected which helps in learning the historical significance of Lake Salda[6]. The full potential for mineralization in India remains largely untapped, presenting significant opportunities for mineral exploration and mining.

The spectral classification uses Spectral Angle Mapper (SAM), Spectral Feature Fitting (SFF), BE algorithms for performing spectral matching. Other techniques for spectral classification are Support Vector Machine (SVM), Maximum likelihood Classifier (MLC), Matched Filtering (MF), Mixture Tuned Matched Filtering (MTMF), Neural Networks (NN) etc. which are supervised classification techniques. The SAM method is a very popular spectral classification technique used for supervised classification. It finds the spectral similarity between sample (or image) spectrum and reference spectrum (ROI) by calculating the angle between them as shown in figure 1. It treats the spectra vectors in a space with dimensionality equal to the number of bands. The smaller angles indicate more similarity to the reference spectrum. The pixels are assigned to the class with the smallest angle. When used with calibrated reflectance data, this technique is relatively insensitive to albedo effects and illumination.

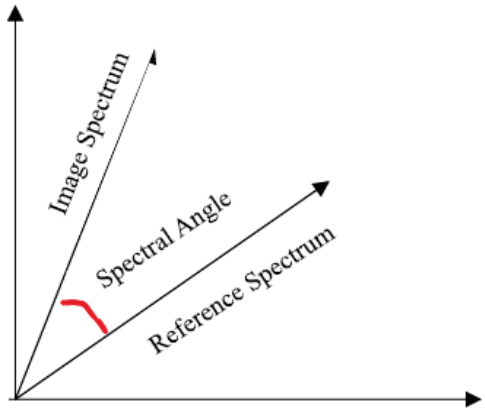


Fig. 1. Spectral Angle Mapper

SFF technique removes the continuum of absorption features from the image spectra and reference spectra. It uses least square fitting to compare the continuum removed image spectra with continuum removed reference spectra. The process of continuum removal is used to find the absorption features from the spectrum. It normalizes all the spectra from the input image by comparing those with continuum curve enabling to find the position and depth of absorption. It compares the absorption feature from each image pixel with the reference spectrum [7]. The continuum curve is formed by fitting a convex hull to the spectrum. Binary Encoding (BE) is also used for comparing the image spectrum with the standard reference spectrum by using the spectrum mean. If the pixel value falls below the mean it is considered as 0 while if it is greater than the spectrum mean value then it is considered as 1 hence named as binary encoding. By using exclusive OR function it encodes the image spectrum to generate the classification image.

The geographical coordinates of location for present work are 19°58’33.1”N 76°30’45.3”E.

Lonar Lake has a mean diameter of 1.2 km and the diameter of meteor crater rim is 1.8 ± 0.05 km.

Study Area: Lonar Crater

Country: India, State: Maharashtra,

District: Buldhana, Place: Lonar.

Latitude-19°58’33.1”N , Longitude-76°30’45.3”E.

LITERATURE REVIEW

Each mineral has a unique reflectance peaks and absorption deeps with different wavelengths. The minerals can be uniquely identified by using these characteristics. Multispectral data used for mineral identification at Lonar Lake, Maharashtra. It suggests that preprocessing can be applied on the multispectral images for noise removal. This data can be analyzed by comparing the mineral spectrum with reference spectra with SAM [8]. Table 1 covers the work done by the Researchers at national and international levels using remote sensing techniques.

Table 1. Research by various Researchers at National and International Level

Sr. no	Title of Paper	Authors	Location or study area	Techniques used	Minerals/ores/ rocks
1	Remote sensing based exploration of structurally-related Minerlizations around Mount Isa, Queensland, Australia[9]	Sandra Jakob, Richard, Carsten (2016)	Queensland, Australia	MTMF, topographical indices	Pb-Zn-Ag mineralization iron stone
2	Remote sensing Exploration of Nb-Ta-LREE-Enriched Carbonatite[10]	Robert Zimmermann, Melanie, Louis,Richard (2016)	Epembe/ Namibia)	SFF, MNF, MRSFF, SOM, Decision Tree	Nb-Ta-LREE carbonatite
3	Lithological Discrimination and Mapping using ASTER SWIR Data in the Udaipur area of Rajasthan, India[11]	Chandan Kumara, Amba Shetty, rich Sharma, Simit Raval, (2015)	Udaipur area of Rajasthan, India	Cross-track correction, FLAASH, ICA, MNF	Conglomerate, mica, granite, quartzite, gneiss, phyllites, dolomitic and calcific marble, pegmatites
4	Prospecting for Hydrothermal Mineral Deposits in the Himalaya using Short-Wave Infrared Spectroscopy[12]	H. Govil (2016)	Himalaya	OO image Classification, SAM, SFF	Illite, epidote, quartzite goethite, dolomite, and hornblende
5	Improving Lithological Mapping by SVM Classification of Spectral and Morphological Features: The Discovery of a New Chromite Body in the Mawat Ophiolite Complex[13]	Arsalan Othman, Richard Gloaguen (2014)	Kurdistan, NE Iraq	SVM, SAM	alunite, kaolinite
6	Effects Of The Multi-scaled Band Partitioning on the Abundance Estimation[14]	Charoula Andreoua, F Halbritterb, D Roggec,Rupert Müllera (2017)	Cuprite, Nevada	MSBP, K-means, endmember extraction	alunite, kaolinite
7	Detecting and mapping different types of iron mineralization in Sangan mining region, NE Iran, using satellite B2image and airborne geophysical data[15]	Nazi Mazhari1, Azadeh Malekzadeh Shafaroudi and Majid Ghaderi(2017)	Sangan, NE Iran	band ratio, PCA, SAM, constrained energy minimization	magnetite, limonite hematite and goethite
8	Nontronite mineral identification in nilgiri hills of tamil nadu using hyperspectral remote sensing [16]	M. Vigneshkumar and Kiran Yarakkula (2017)	Nilgiri hills of tamil nadu	FLAASH, MNF, PPI,SAM	Nontronite
9	Sub-Pixel Mineral Mapping Using Eo-1 Hyperion Hyperspectral Data [17]	Chandan Kumar, Amba Shetty, Simit Raval, Prashant Kumar Champatiray c, Richa Sharma (2014)	mountainous terrain of Rajsamand district of Rajasthan,	MTTCIMF algorithm	lead, zinc, and copper etc, surface minerals like montmorillonite, illite, phlogopite, dolomite and chlorite
10	Recognition of Minerals Using Multispectral Remote Sensing Data:A Case Study in the Sultanate of Oman [18]	Sankaran Rajendran1 and Sobhi Nasir (2014)	Rusayl and Muscat, Sultanate of Oman	SAM supervised classification	carbonate, silicate minerals
11	Spectral transformation of ASTER and Landsat TM bands for lithological mapping of Soghan ophiolite complex, south Iran[19]	Mohsen Pournamdari, Mazlan Hashim, Amin Beiranvand Pour (2014)	South Iran	correlation coefficient (CC), OIF, band ratio (BR), PCA	Soghan ophiolite complex

Hyperspectral remote sensing allows for the measurement of hundreds of spectral bands. The unique spatial or spectral datasets obtained through sensors can be used for analysis of surface mineralogy [20]. The analysis shown accurate mapping for minerals such as kaolinite, hematite, alunite, goethite, sericite and chromite. Their geologic applications are well explained in. For the extraction of useful information from hyperspectral images two techniques can be used depending on the spectral space and other depending on the feature space. The different feature space based techniques were applied on multispectral data while MF technique was used on hyperspectral images to obtain the enhanced outcomes.

Conclusion from above papers analysis shown the impactful Ness of hyperspectral images for spectral classification and mapping. Hence the proposed methodology emphasize on use of hyperspectral data for spectral classification. The spectral signatures are extracted from the satellite image and used for spectral Classification which helps in classifying land, vegetation, different mineral classes, water, bare land, etc.

METHODS

The proposed methodology begins with hyperspectral images acquired from the Hyperion sensor onboard NASA's EO-1 satellite, which captures data across 242 spectral bands. However, several of these bands are adversely affected during acquisition due to atmospheric interference such as water vapor and aerosols. To handle this problem the atmospheric correction is to be performed using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) algorithm.

The hyperspectral data often suffer from various distortions introduced during acquisition, such as atmospheric interference, sensor noise, and defective detector elements. These issues must be addressed through a series of preprocessing steps to ensure the reliability of subsequent analysis. After noise handling, next is the dimensionality reduction. The Minimum Noise Fraction (MNF) transformation has to be performed for dimensionality reduction and noise removal. MNF spectrally isolate the significant bands having eigenvalues more than 1. After preprocessing. The endmembers obtained through MNF are used to construct the spectral library, which is then used for spectral classification and accurate mineral identification. The methodology steps are as shown in figure 2.

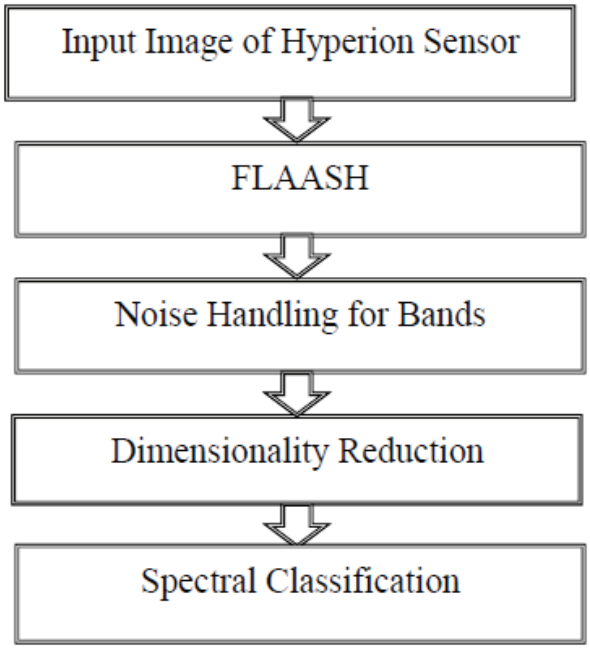


Fig. 2 Methodology for Spectral Classification

RESULTS

The Hyperion dataset for spectral classification. The images are preprocessed first for atmospheric correction using FLAASH and then destriping for removing bad columns from the image. It is necessary to remove the noise available in the images. The noise removal and dimensionality reduction are performed by using MNF technique. The significant bands obtained through MNF were selected having more eigenvalue for it. Once the optimized data is obtained, then Spectral classification is performed on this data using SAM algorithm. The maximum angle selected for classification is 0.600. The ROI classes are formed and saved for creation of spectral library. The spectral library built is compared with standard spectral library for spectral analysis and the mineral identification. The resultant classification image is as shown in figure 3.

The Lonar lake water (central Magenta color) and nearby lake (blue color) are classified and marked with different colors indicating the different characteristics

of both water bodies. The ground truth ROI and classification output ROI are matched. The confusion matrix is as shown in figure 4. The accuracy of SAM is 84.21% wit 0.8215 Kappa Coefficient. Bright green color indicating vegetation available at the top edges of left rim.

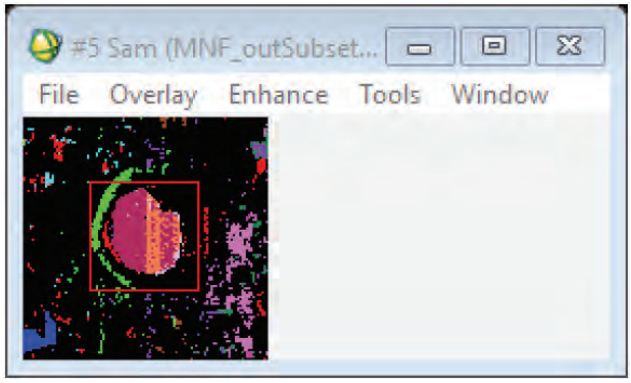
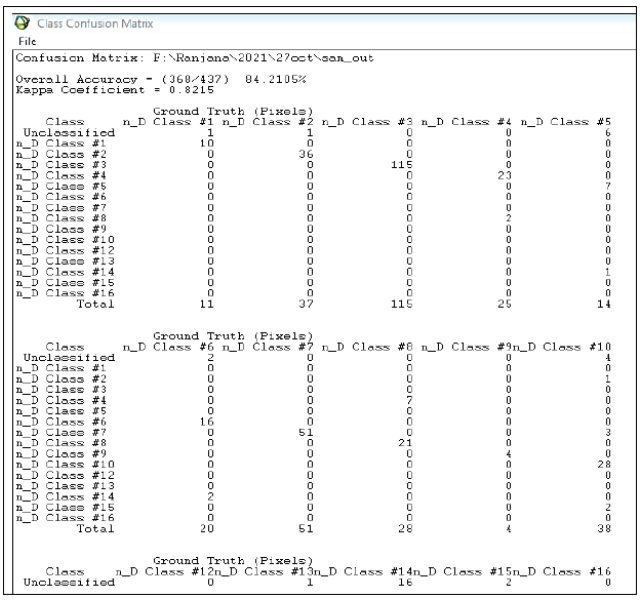


Fig. 3 Spectral Classification Image


Class Confusion Matrix

File

Confusion Matrix: F:\Ranjana\2021\27oct\san_out

Overall Accuracy = (360/427) 84.2105%
Kappa Coefficient = 0.8215

Class	Ground Truth (Pixels) n_D Class #1	n_D Class #2	n_D Class #3	n_D Class #4	n_D Class #5
Unclassified	1	1	0	0	6
n_D Class #1	10	0	0	0	0
n_D Class #2	0	36	0	0	0
n_D Class #3	0	0	115	0	0
n_D Class #4	0	0	0	23	0
n_D Class #5	0	0	0	0	7
n_D Class #6	0	0	0	0	0
n_D Class #7	0	0	0	0	0
n_D Class #8	0	0	0	2	0
n_D Class #9	0	0	0	0	0
n_D Class #10	0	0	0	0	0
n_D Class #12	0	0	0	0	0
n_D Class #13	0	0	0	0	0
n_D Class #14	0	0	0	0	1
n_D Class #15	0	0	0	0	0
n_D Class #16	0	0	0	0	0
Total	11	37	115	25	14

Class	Ground Truth (Pixels) n_D Class #6	n_D Class #7	n_D Class #8	n_D Class #9	n_D Class #10
Unclassified	2	0	0	0	4
n_D Class #1	0	0	0	0	0
n_D Class #2	0	0	0	0	1
n_D Class #3	0	0	0	0	0
n_D Class #4	0	0	7	0	0
n_D Class #5	0	0	0	0	0
n_D Class #6	16	0	0	0	0
n_D Class #7	0	51	0	0	3
n_D Class #8	0	0	21	0	0
n_D Class #9	0	0	0	4	0
n_D Class #10	0	0	0	0	28
n_D Class #12	0	0	0	0	0
n_D Class #13	0	0	0	0	0
n_D Class #14	2	0	0	0	0
n_D Class #15	0	0	0	0	2
n_D Class #16	0	0	0	0	0
Total	20	51	28	4	38

Class	Ground Truth (Pixels) n_D Class #12	n_D Class #13	n_D Class #14	n_D Class #15	n_D Class #16
Unclassified	0	1	16	2	0

Fig. 4 Confusion Matrix

CONCLUSION

The proposed work focused on studying the work by different researchers in the field of remote sensing. The hyperspectral images are having high spectral resolution hence more prominent in the mineral mapping and lithological discrimination. Bad image band handling, Destriping and atmospheric correction for preprocessing are applied by observing the images. The subset spectra obtained after preprocessing can be analyzed using SAM to enhance the results. These spectra then compared with reference spectra and minerals can be identified. The proposed work utilized Hyperion sensor data for spectral classification at Lonar Crater. The SAM technique delivered the accuracy of 84.21%. The proposed methodology used EO-1 Hyperion data for spectral classification.

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Enhancing the Efficiency of Solar PV Module Using Artificial Intelligence Based Maximum Power Point Tracking

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ABSTRACT

Solar cells convert sunlight's energy into electrical energy. The solar panel's efficiency is decreased due to various factors such as the solar radiation, surrounding air temperature, the thickness of the solar panel, the wavelength of the light falling on the solar cell, shading effect, the angle of solar light falls on the solar cell, dust deposited on the solar panel, recombination of holes and electrons. Improving the efficiency of solar PV modules is a big challenge in the solar power conversion system. The Maximum Power Point Tracking (MPPT) techniques often achieve local maximum points but cannot reach global maximum points. The proposed Artificial Intelligence (AI) based MPPT technique attains the global maximum point with the fast-converging speed, low steady state error and high efficiency. However, the AI-based MPPT techniques suffer from intensive computations and higher costs. This paper proposes an artificial intelligence-based machine learning MPPT technique to enhance the efficiency of solar panels. A 260-watt solar panel power measurement experimental setup is implemented to analyze the power output and efficiency for any variation in solar radiation. In the proposed AI-based machine learning MPPT technique, a linear regression model is trained with large amounts of data set for all weather conditions. The proposed AI-based machine learning MPPT technique predicts the optimal duty cycle for the power optimizer to obtain maximum power output. The experimental result shows that a considerable amount of energy is saved annually and the amount of CO2 emission is also reduced.

KEYWORDS *: Artificial intelligence, MPPT, Solar PV module, Power optimizer, Solar energy, Machine learning.*

INTRODUCTION

Renewable energy usage is gaining momentum, particularly solar power, which is widely used due to its simplicity, low cost, and high efficiency. Renewable solar energy is available in large quantities for power generation and is becoming increasingly popular to tackle the pollution and non-sustainability of conventional energy sources. Fossil fuels, oil, and natural gas are depleting daily, so everyone is moving towards solar power. The significant advantage of solar power is that the solar power is a clean form of energy available in abundance over conventional energy resources.

Solar power generation has certain limitations, such as the varying nature of solar irradiance, air temperature, and nonlinear characteristics of the solar cell. These limitations result in unsatisfactory power extraction from the solar panels. The Solar P-V curve shown in Figure 1 has two regions: the constant voltage region lies on the right-hand side of the Maximum Power Point (MPP) and the constant current region lies on the left-hand side of the MPP.

A DC-to-DC power converter is utilized in solar power generation to obtain maximum power from the solar panel [1]. The converter's duty cycle is continuously adjusted to move the operating point towards MPP. The duty cycle is adjusted based on two consecutive power measurements (Pnew & Pold) and two consecutive voltage measurements (Vnew & Vold) as per the following conditions.

i) If $P_{new} > P_{old}$ & $V_{new} > V_{old}$ then D=D-ΔD

ii) If $P_{new} < P_{old}$ & $V_{new} < V_{old}$ then D=D-ΔD

iii) If $P_{new} < P_{old}$ & $V_{new} > V_{old}$ then D=D+ΔD

iv) If $P_{new} > P_{old}$ & $V_{new} < V_{old}$ then D=D+ΔD

v) If $P_{new} = P_{old}$ & $V_{new} = V_{old}$ then D=D

Where,

D is duty cycle and ΔD is the change in duty cycle.

P_{new} = present value of solar power

P_{old} = previous value of solar power

V_{new} = Present value of solar PV module voltage

V_{old} = previous value of solar PV module voltage

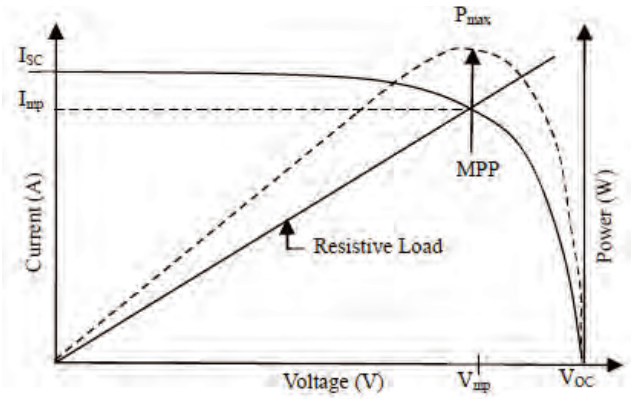

Fig. 1. i-v and p-v curves

There are many nonintelligence methods, such as hill climbing, incremental conductance, and constant voltage control, and many artificial intelligence-based methods are available for the converter to achieve the MPPT [2,3]. Despite many advancements in Solar PV technology, increasing the efficiency of solar panels is still a big challenge. Many researchers and industry stakeholders are working to enhance the efficiency of solar PV module. In addition, increasing the efficiency of the solar PV module will reduce the area of the solar panel, land requirement, equivalent CO2 emissions from coal-based thermal power resources, and the cost of power generation [4,5,6].

This paper describes a new artificial intelligence-based machine learning MPPT for the 260-watt solar panel to capitalize maximum power output, enhance the efficiency of the solar panel, and reduce carbon emissions.

LITERATURE SURVEY

One way to improve efficiency is to apply engineering concepts and devise a new semiconductor material. Quantum dot microscopic crystalline semiconducting particles could make our solar PV modules more efficient [7,8]. A single solar junction cell's theoretical maximum conversion efficiency is around 30% [9,10]. If more junctions are added, then the efficiency can still be increased.

The basic principle behind the MPPT algorithm is the impedance matching between the Solar PV module and load using a controllable DC-to-DC converter. The parabolic prediction MPPT technique requires 3 points on the PV curve to obtain the new operating points with a quadratic polynomial equation. In this method, a reference point is fixed, and 3 points are compared with it. The point with the lowest power is omitted. The drawback of this method is the requirement for a more significant number of points on the PV curve.

I-V Curve fitting is a method similar to parabolic prediction. It utilizes several I-V points to extract physical parameters and plot an estimated I-V curve for MPPT. The drawback of this method is that the operating point may diverge from the MPP.

The MPP locus method is a typical hybrid step size method. This method relies on MPP occurring in a straight line under different irradiance conditions. If there is a sudden change in irradiance, variable step size will be implemented. The drawback of the MPP locus method is that it requires fixing variable and fixed step sizes.

In the constant voltage control method, the solar panel voltage is compared with a reference voltage and an error signal is generated. This error signal corrects the duty cycle, which results in the power converter's operating point moving to MPP. The drawback of the constant voltage control method is that the operating point may diverge from the MPP.

Fuzzy Logic Control (FLC) is an intelligent technique used in a system whose output is subject to change. FLC can be used in solar power systems as an MPPT technique. The FLC based MPPT technique consists of three stages of implementation [11,12]. The first stage is fuzzification, in which the error and change in the

error of the ratio of power and voltage are set as inputs [13,14]. The second stage is the rule base, in which the input variables and output variables are related. The third stage is defuzzification, which converts the output variable into a crisp value. FLC exhibits good tracking, but it suffers from the risk of drift.

Artificial Neural Network (ANN) acts similarly to the basic principles of human brains. ANN has an input layer, an output layer and hidden layers. The input layer typically receives information from the outside world, which the ANN analyzes and learns. This information will be passed through one or more hidden layers and then transformed into valuable data. The output layer provides output as a response of ANN for the corresponding input [15,16]. In solar power systems, the ANN is trained to understand the nonlinear relationship between voltage and current (V-I) and the solar PV module's power and voltage (P-V). After the training, the ANN is tested with the training dataset to analyze its performance. The error in its performance is feedback to the ANN for further adjustment of its weights [17]. The ANN receives voltage, current, irradiance and temperature as inputs and is trained to provide data corresponding to the MPP. The ANN has good tracking speed in reaching MPP, low transient response and low ripple under the actual climatic conditions of solar irradiance and temperatures. However, the ANN has certain limitations, such as the requirement of a large training data set, low tracking speed, regular training for climatic conditions, and complexity and time consumption.

The Genetic Algorithm (GA) can solve optimization problems with a superior capability over other AI methods. In GA, the initial population of chromosomes, consisting of series of 1s and 0s, is transformed into a new population using the genetic operators of selection, crossover and mutation. The GA is initiated by the parent of solar PV voltage and its fitness function is the output power [18,19]. The GA is capable of reaching the global minimum instead of local minimum point. The GA has drawbacks of slow tracking speed and dependency on initial population.

The Ant colony is a computational technique for solving many optimization problems, similar to ants searching for food. The ant colony method determines the operating point of a solar PV system to trap maximum power [20]. It has certain disadvantages, such as convergence to suboptimal solutions and poor response in dynamic climatic conditions.

The existing MPPT techniques have drawbacks, including longer training time, dependency on initial conditions, complexity, and higher cost. A better MPPT technique is required to overcome the above mentioned disadvantages to receive maximum power and reduce carbon emissions. This paper proposes an AI-based machine learning MPPT algorithm with a linear regression model.

ARTIFICIAL INTELLIGENCE FOR SOLAR POWER

Artificial Intelligence refers to the intelligent ability of machines, particularly computers, to determine output based on training with a large amount of data. It is a research field with applications in all engineering branches, and its learning and intelligence make the user achieve their desired performance. In AI, each specific research problem is split into many subproblems and solved easily with intelligence. Artificial intelligence solves many problems, such as reasoning and problem-solving, knowledge representation, planning and decision-making, learning natural language processing and many more. The two sets of artificial intelligence are Machine learning and its inner subset deep learning. They can be used for various applications to reach the desired goals.

Machine Learning

Linear regression is a supervised learning algorithm used in many AI applications. Machines are playing a significant role in making humans' lives easier. Human beings have been learning from past experiences and intelligence for hundreds of years, whereas machines, specifically computers, have begun to learn. In today's world, computers are programmed to satisfy the needs of human beings. Machine learning focuses on designing a system to learn and make decisions based on experience. Machine learning is the central part of many systems designed for specific functions. Significant examples of machine learning are self-driving cars, artificial intelligence robots and many more.

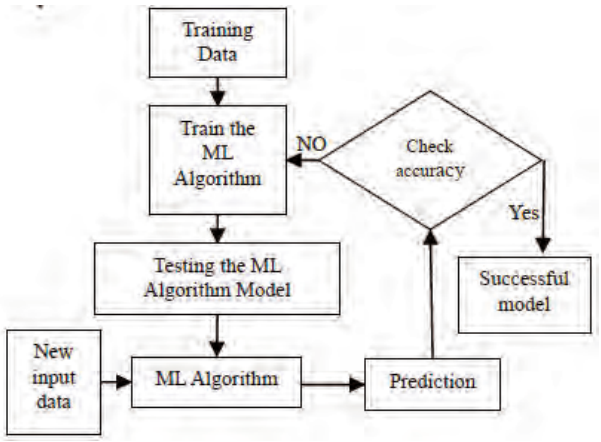

Fig. 2. Flowchart of Machine Learning algorithm

Machine learning enables computers to do specific tasks rather than being programmed to make decisions. These programs are developed to learn and improve themselves over time for new kinds of data that are not in the training data set. The sequence of operation of the machine learning algorithm is shown in Figure 2. A Machine learning algorithm is developed using a training data set. A new set of inputs is applied to the machine learning model, which determines the output. The output is evaluated for accuracy. The developed machine-learning AI model is accepted if the accuracy is within the permissible limit; however, if the accuracy is not within the permissible limit, then the machine-learning AI model is trained further until the desired accuracy is reached.

Supervised learning

Supervised learning consists of input and output variables with the related mapping function. In supervised learning, the algorithm understands the mapping function and learns the input to the output. The training data set includes all possible input and corresponding desired output. The input training data may be any data from the image or the value of a database row. For each input, the expected value is related to a value that can be discrete or continuous. The model learns the input data pattern for continuous or discontinuous values that generate the desired output. The trained algorithm can determine the correct output for the new input data not included in the training input data set. In supervised learning, the output is monitored and the algorithm is modified till the desired performance is reached. Supervised learning is used in many applications such as Biometric attendance, speech recognition, weather apps, banking, healthcare, and retail. Supervised learning is used in this paper.

Linear regression model

Regression analysis is one of the predictive modeling approach that investigates the relationships between dependent and independent variables. The three major uses of regression analysis are determining the strength of predictors, forecasting an effect, and trend forecasting. Regression analysis helps us understand how much the dependent variable changes with the change of one or more independent variables.

The linear regression can be expressed as

$y = mx + c$

Where y is a dependent variable, x is an independent variable and c is constant.

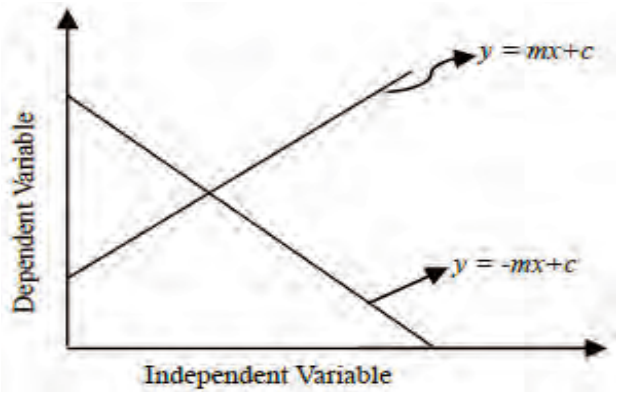

Fig. 3. Linear regression straight lines

Every value of a variable x has a corresponding value of a variable y if it is continuous. In the linear regression model, our data is modeled using a straight line. Figure 3 shows the relationship between independent and dependent variables in terms of positive and negative regression straight lines. Linear aggression is used with continuous variables. The prediction of linear regression is the value of the variable.

Maximum Power Point Tracking

Maximum Power Point Tracking is a clever technique that can improve the response of variable power sources. The voltage decreases when more current is drawn from the power source and vice versa. In both cases, solar

power generation is low.

Some ratio between voltage and current must be determined to get maximum solar power and there must be a balance between voltage and current. So, to transfer maximum power from the solar panel, a method called MPPT is employed to operate a DC-DC buck converter.

The MPPT uses an electronic circuit and an algorithm. This algorithm matches the impedance between the Solar PV module and the load, which is necessary for maximum power transfer. The DC-DC buck converter successfully achieves impedance matching.

Impedance matching is obtained by controlling the DC-DC buck converter's Duty Cycle (DC). The power transfer is calculated by observing the solar PV module's voltage and current. The DC is calculated using the MPPT algorithm and the converter is adjusted accordingly. Adjusting the DC-DC buck converter's duty cycle changes the solar PV module's output voltage to reach the maximum power point.

MPPT Algorithm

Incremental conductance is a basic method used in the MPPT algorithm. In this method, the MPP is reached by balancing the impedance of the solar PV module and the converter. The power is adjusted by increasing or decreasing the DC. Figure 4 shows the incremental conductance based MPPT.

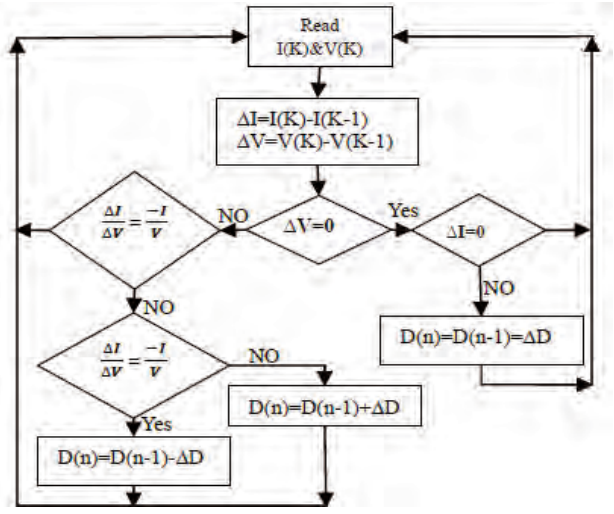

Fig. 4. Flow chart of Incremental conductance method

The machine learning algorithm requires more data on independent and dependent variables. The independent variables of a Solar PV module are voltage, current, change in voltage and change in current and the dependent variable is the duty cycle. The incremental conductance method generates data for the proposed AI-based machine learning MPPT technique.

Power optimizer

The power optimizer is a DC-DC buck converter. The voltage and current of the Solar PV module are measured and sent to the controller. The controller stores this information and calculates the change in voltage and the change in current from the last two readings. The current, voltage, change in current, and change in voltage are sent to the machine learning algorithm.

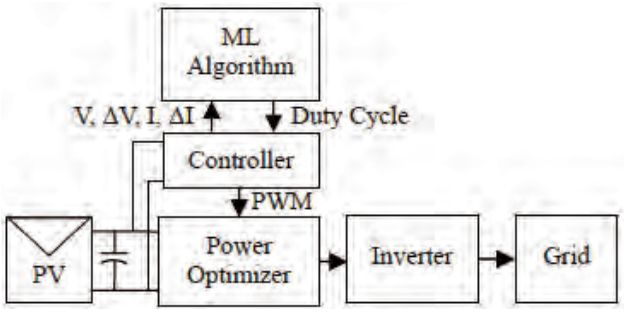

Fig. 5. Solar power conversion using Machine Learning

Figure 5 shows the machine learning algorithm for maximum power transfer from a solar PV module. The machine learning algorithm is developed using a linear regression model. The trained linear regression model predicts the duty cycle to achieve the maximum PowerPoint. This duty cycle is sent to the controller, which develops the Pulse Width Modulated (PWM) signal for the power optimizer.

RESULTS AND ANALYSIS

A 260W black colored monocrystalline high purity silicon solar panel of open circuit voltage 37.6 volts and short circuit current of 8.74 amperes is used in our experimental setup. Voltage and current sensors connected in the system read the current and voltage of the solar PV module and feed the data to the controller. The controller calculates the change in voltage and current from the data it received from the last two consecutive intervals of time.

The machine learning algorithm in the Linear Regression model is implemented on a desktop computer. The

linear regression model is developed to predict the DC for the power optimizer. The input data, such as voltage and current of the Solar PV module, are collected in real time from 8:00 a.m. to 5:00 p.m. for every one minute. In the same way, the input data, such as change in voltage and change in current, are collected from the controller for every instant of 1 minute. The output data, namely the power optimizer's duty cycle, is predicted from the Machine learning algorithm for every instance of 1 minute.

The controller calculates the input data, such as change in voltage and current in the category of independent variable and duty cycle in the category of dependent variable. Out of all the data collected from the sensors and controller, 80% is used rigorously to train the linear regression model. The remaining 20% of data is used rigorously to test the model. The successful linear regression model determines the DC for the present new data. The 260 Watts solar PV module power measurement Experimental Setup is shown in Figure 6.

Fig. 6. 260Watts solar PV power Measurement Experimental Setup

The controller adjusts the width of the PWM signal by an updated duty cycle it receives from the Linear regression model implemented in the computer. The power optimizer changes the operating point to get impedance matching between the solar PV module and across the DC-DC power converter for maximum power transfer from the solar panel.

Efficiency

Solar irradiance is measured using a pyranometer to calculate solar input power. The output power is then calculated by measuring the solar PV module's voltage and current. The solar panel of the experimental setup is exposed to sunlight from 8 a.m. to 5 p.m., readings are taken every hour, and the efficiency is calculated. The efficiency of the sunlight-exposed Solar PV module with AI-based machine learning MPPT and without AI-based MPPT algorithms is calculated and given in Table 1.

The efficiency of the 260Watts Solar PV module increases from 8.00 a.m. to 5.00 p.m. when the AI-based machine learning MPPT algorithm is used. The Maximum efficiency of the solar PV reaches 15.05%, obtained at 2:00 p.m.

The solar panel of the Experimental Setup is exposed to the meticulously designed light arrangement in the laboratory. Switching on one or more combinations of lights can simulate various irradiances in the laboratory.

Table: 1 Response of the Experimental Setup by exposing the solar PV module to the sunlight

Time	Solar irradiance (W/m^2)	Solar PV module Temperature (°C)	Solar PV Voltage (Volt)	Solar PV Current (Ampere)	Power output (Watts)	Efficiency without AI (%)	Efficiency with AI (%)
8.00am	870	21.02	28.2	6.9	194.58	12.41	13.55
9.00am	980	23.13	30.1	7.3	219.73	12.38	13.59
10.00am	1100	25.68	34.2	7.5	256.5	13.79	14.13
11.00am	1120	28.12	33.6	7.6	255.36	12.99	13.82
12.00Noon	1130	30.02	34.3	7.3	250.39	13.09	13.43
1.00pm	1150	31.35	35.2	7.8	274.56	13.66	14.47
2.00pm	1180	32.78	37.1	7.9	293.09	14.39	15.05
3.00pm	1170	32.57	36.8	7.5	276.00	13.89	14.29
4.00pm	1090	32.03	34.5	6.9	238.05	12.32	13.24
5.00pm	840	31.12	30.1	5.9	177.59	12.18	12.81

Table: 2 Response of the Experimental Setup by exposing the solar PV module panel to light

Combinations of light arrangements	Light irradiance (W/m^2)	Solar PV module Temperature (°C)	Solar PV Voltage (Volt)	Solar PV Current (Ampere)	Power output (Watts)	Efficiency without AI (%)	Efficiency with AI (%)
1.	147	34.0	16.1	1.1	17.71	7.85	8.23
2.	148	34.5	18.3	1.6	29.28	8.07	8.53
3.	350	35.0	22.4	2.3	51.52	8.20	9.05
4.	400	36.0	24.3	2.7	65.61	8.47	9.58
5.	508	38.9	27.1	3.4	92.14	9.21	10.66
6.	688	40.0	28.2	4.1	115.62	11.89	12.08
7.	686	40.5	29	5.3	153.7	13.31	14.22
8.	686	42.0	32.3	5.4	174.42	14.68	15.10
9.	706	46.0	34.4	5.8	199.52	15.32	16.34

The efficiency of the Solar PV module when exposed to lights with AI-based machine learning MPPT and without AI-based MPPT algorithms is calculated and given in Table 2.

In all the combinations of lights, the AI-based machine learning MPPT algorithm produces maximum efficiency compared to without the AI-based MPPT algorithm. The solar PV module's maximum efficiency when exposed to light in the laboratory is 16.34% when all nine lamps are switched on.

Output analysis

Output power is calculated by measuring the Solar PV module's voltage and current for every instant of time. The artificial intelligence-based machine learning MPPT algorithm optimizes the operating point of the PV curve to receive maximum output power from the solar panel all the time from 8:00 a.m. to 5:00 p.m. The AI-based machine learning MPPT algorithm always produces maximum power output from the Solar PV module. So, the AI-based machine learning MPPT algorithm provides a significant improvement over the MPPT algorithm without AI.

Ability of the Artificial Intelligence based machine learning MPPT algorithm

Artificial Intelligence-based machine learning MPPT algorithm is implemented using Python coding. The linear regression model is developed for independent and dependent variables. The Solar PV module output power and efficiency are determined with and without the AI model. The solar PV module output power and efficiency significantly improve when an AI-based machine learning MPPT algorithm is used.

Comparative analysis

The AI-based machine learning MPPT algorithm is implemented with a linear regression model for a 260-watt Solar PV module to maximize output power. The AI-based machine learning MPPT algorithm consistently produces a maximum power output and higher efficiency compared to the incremental conductance method-based MPPT algorithm.

The efficiency of the Solar PV module with an AI-based machine learning MPPT algorithm and without an AI-based MPPT algorithm are shown in Figure 7. The comparison shows that the AI-based machine learning MPPT algorithm produces higher efficiency than the incremental conductance-based MPPT algorithm.

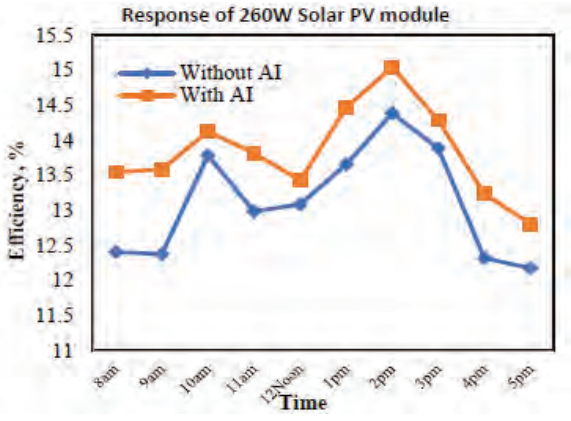

Fig. 7. Efficiency of 260 watts solar PV module with AI and without AI

The energy produced by a 260-watt solar PV module using the AI-based machine learning MPPT algorithm is 2435.85 Watt-hours per day, while the incremental conductance-based MPPT algorithm produces only 2310.98 Watt-hours per day. The AI-based machine learning MPPT algorithm results in an annual energy generation of 889 Kilowatt-hours compared to the 843 Kilowatt-hours produced by the incremental conductance-based MPPT algorithm. This represents a significant reduction of 0.81 pounds of CO2 emissions per kWh.

CONCLUSION

The AI-based machine learning MPPT algorithm is implemented for a 260-watt solar PV module power system and is compared with the incremental conductance-based MPPT algorithm. A linear regression model is developed in machine learning to establish the relationship between input and output numerical variables. The linear regression model learns to model the output dependent variable as a function of input independent variables. The experimental setup for the power measurement of a 260-watt solar PV module is implemented to analyse the performance of the AI-based machine learning MPPT technique.

The solar PV module of the experimental setup is exposed to sunlight and light arrangement in the laboratory to measure power and determine efficiency. AI-based machine learning MPPT technique is developed in desktop computer. The linear aggression model is implemented in Python coding, which will run on the desktop computer to predict the DC for the power optimizer. The AI-based machine learning MPPT algorithm predicts the DC for any rabbit change in irradiance, cell temperature or load conditions.

The AI-based machine learning MPPT technique produces more power output than the incremental conductance-based MPPT technique. The efficiency of the solar PV module is increased in the AI-based machine learning MPPT technique compared to the incremental conductance-based MPPT technique. The experimental findings show that 46 Kilowatt-hours of more energy is generated annually with the AI-based MPPT algorithm than without the AI-based MPPT algorithm and an equivalent amount of CO_2 emission is also reduced.

This paper provides the latest developments in artificial intelligence-based MPPT techniques for solar power systems.

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College Admission Chatbot

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ABSTRACT

This project introduces an AI chatbot capable of responding in real time to inquiries on admissions, courses, fees, faculty members, events, and campus amenities. The AI chatbot uses. Artificial Intelligence (AI), through understanding what the user has inquired to provide the information the user needs in an effective manner . The system relies on machine learning models to recognize intents while using a dataset to provide complete and accurate information . The chatbot can integrate with websites, mobile applications and messaging apps . The chatbot will alleviate some of the burden placed on college administration by automating responses to frequently asked questions. The chatbot will also add to the user experience, and it can provide continuous support with 24/7 engagement. The design for the user interface for this chatbot is provided in HTML, CSS, and JavaScript for easy integration into a college website or mobile application.

INTRODUCTION

College students and prospective visitors often need information about the college, such as schedules, upcoming events, Faculty, examinations dates, assignments, and deadlines. Calling someone, going through the website or email to reach them, takes a long time, and they have to wait a long time for a reply. Chatbot interaction is increasingly used over in-person support showing a trend in communicating. An-AI based chatbot can solve this problem, serving as a passive system, as the chat bot will be available online 24/7 to help users resolve doubts from anywhere with internet.

The purpose of this research is to determine the software components needed to develop a chatbot support system via machine learning and natural language processing which can take voice/text input. In this research, we will develop a web-based chatbot which can be included in a college website that can provide answers to questions asked by students or parents easily, accurately, and correctly. This system will not only reduce the load on university departments but will provide interaction between students and the college, which does not require the presence of a person talking to the person at the college or university.

LITERATURE REVIEW

Purpose and Benefits of Chatbots in Educational Settings

Addressing Inefficiencies

- The admissions process for institutions of higher education can also be competitive and complicated, and students may have difficulty identifying a "fit" for their college needs, wants, and desires.
- Even traditional inquiry forms such as on campus visits, telephone calls, or email can be slow, inconvenient, and take time due to the wait time and limited availability of staff, leading to student frustration and additional workload for the colleges and universities.
- Chatbots provide a much-needed answer to student inquiries, as they provide fast, automated, and standardized answers to frequently asked questions, eliminating human responsibility and administering routines.

Enhancing User Experience and Accessibility

- Chatbots provide a familiar interface (often graphical, like a messaging app) which permits students and parents to obtain information in an asynchronous manner wherever and whenever an internet connection exists.
- They enhance the institution's standing and image by delivering a higher quality of advice and decreased errors.
- Chatbots may facilitate personalized advice using applicant data on academic performance, department preferences and minority status, to produce personalized college recommendations.

They can also improve student engagement and assist faculty members by automating classroom administrative tasks.

METHODOLOGY

Data Collection and Preprocessing

One of the first steps is to collect as much complete historical admissions data as possible. This includes data regarding student academic measures (i.e. MHTCET or JEE/CET scores and percentage scores) and student preferences, even minority status.

There are many sources of data including educational institutions, examination authorities, official university websites, social media, and data from academic advisors. The data you collect will also include data collected using web scraping.

Preprocessing is crucial for data quality and machine readability. Key preprocessing steps include:

Dealing with missing values, normalizing predictors, and encoding categorical variables.

Text cleaning: removing irregularities, mistakes, redundancies and correct typographical errors and abbreviations, and some noisy characters, punctuation and stop words.

Lemmatization and Part-of-Speech (POS) Tagging, in conjunction with resources such as WordNet, can be useful in collating the various inflected forms of words (for instance, requiring and requirement).

When processing Vietnamese input, one of the preprocessing steps is adding diacritical marks for correcting spelling and compatibility with datasets.

Converting from number data to text could be useful for processing text data.

Datasets are often manually labelled by intent or subject area. For improving robustness, questions have been created with similar intents by changing the words (synonyms) or the order of sentences (active and passive), question (question stem).

Knowledge bases are typically designed to contain various information such as, predetermined questions/answers, further dynamic information (extent of tuition fees, dates for admission), and media files (photographs, audio clips, PDF documents).

RESULTS AND DISCUSSION

Literature consistently supports the effectiveness and transformative power of college admission chatbots to improve traditional admission processes in terms of access, efficiency, and user-focus. Ongoing research efforts maintain promised advantages by improving data management, increasing contextual understanding, and integrating more advanced AI methods to develop increasingly viable and human-like systems.

College Recommendation and Chatbots: Various articles discuss the emergence of AI-based chatbots that respond to inquiries about college, admission, and career guidance. These services provide instant responses to any student or parent inquiry, 7 days per week, 24 hours each day. The overall goal is for these services to cut down administrative work while making the experience quicker, easier, and more personal.

Methodologies: The operation of chatbots is dependent on Natural Language Processing (NLP), machine learning algorithms (for example Naive Bayes, Random Forest, Support Vector Machines (SVM), Decision Trees) and pattern matching for query analysis, intent classification and generating responses. Some chatbots integrate with Rasa, Dialog-flow or Botsify for example.

Personalised Recommendations: Beyond general queries, systems are designed to offer personalised college recommendations based on academic records, entrance exam scores (e.g., MHTCET, JEE, CET), extracurricular activities, and preferences.

Performance and Challenges: Chatbots have been shown to classify intents with high accuracy, the reported accuracies ranging from 88% to 97.1%. Despite the successes, challenges do persist including data quality issues, limitations of the static dataset, the complexity of human language, and the inability to update manually. There is also recognition around the importance of a human-like interaction and being able to account for errors gracefully.

FUTURE TRENDS

While these models have the potential to sway the communicative landscape, the theoretical contributions also spotlight areas for the continuing work: Data Quality and Quantity: The capabilities of these models, in theory, are dependent on the quantity, diversity, and quality of training data. Challenges, such as the phenomenon of "mode collapse" (failures in the generator to produce diverse samples), and the reliance on updating knowledge bases manually, at least once a year for faculty (e.g. August) are a concern. Interpretability and Generalisability: While AI models can display accuracy, they can be less interpretable (understanding why they are making such decisions), especially with deep learning models. This continues to be a theoretical challenge when fostering trust and using ethical, unbiased decisions, especially for more sensitive areas such as career guidance. There is also the issue of continuously establishing generalisability of models for varying user inputs and scenarios. Understanding Nuance and Ambiguity: Human language is nuanced and ambiguous. Chatbots - especially in their gently developmental stages - have difficulty with inputs that they do not recognize, grammatical errors, and context misunderstandings. Future theoretical work will aim for models to process and respond to inputs with greater complexity and nuance. Integrating with Current Systems: Finally, in theory, chatbots should have the capability to operate independent of, yet integrate with, existing university information systems (ERP, student information systems, etc.). However, this is complicated in practice with data synchronisation and API creation. Ethical Considerations: The theoretical discussion acknowledges ethical dilemmas, including privacy, trust, and potential misuse (e.g., deepfakes, though not directly for admission chatbots). Responsible development requires addressing these concerns.

Discussion

College Recommendation Chatbots: Various articles discuss the emergence of AI-based chatbots that respond to inquiries about college, admission, and career guidance. These services provide instant responses to any student or parent inquiry, 7 days per week, 24 hours each day. The overall goal is for these services to cut down administrative work while making the experience quicker, easier, and more personal. Methodologies: The operation of chatbots is dependent on Natural Language Processing (NLP), machine learning algorithms (for example Naive Bayes, Random Forest, Support Vector Machines (SVM), Decision Trees) and pattern matching for query analysis, intent classification and generating responses. Some chatbots integrate with Rasa, Dialog-flow or Botsify for example. Personalised Recommendations: Beyond general queries, systems are designed to offer personalised college recommendations based on academic records, entrance exam scores (e.g., MHTCET, JEE, CET), extracurricular activities, and preferences. and Performance and Challenges: Chatbots have been shown to classify intents with high accuracy, the reported accuracies ranging from 88% to 97.1%. Despite the successes, challenges do persist including data quality issues, limitations of the static dataset, the complexity of human language, and the inability to update manually. There is also recognition around the importance of a human-like interaction and being able to account for errors gracefully.

CONCLUSION AND FUTURE SCOPE

These materials show a multidisciplinary response to the emerging trends in engineering and technology with the commonality of AI and machine learning. All sectors are leading to innovative solutions and proven efficiencies, decision making, and accuracy improvements in multiple sectors, including health care, industrial automation, education. finance, and Education.

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Cognitive Strain and Psychological Wellbeing in Tech Industry Workers: The Impact of Always-On Culture and Remote Work

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ABSTRACT

This comprehensive study explores the cognitive, emotional, and behavioral effects of the always-on digital culture and the evolving nature of remote work on employees in the technology sector. By integrating psychological theories (e.g., JD-R Model, Cognitive Load Theory), occupational health frameworks (e.g., WHO guidelines, Maslach Burnout Inventory), and insights from human-computer interaction (HCI), this multidisciplinary research adopts a convergent mixed-methods design.

Quantitative surveys and qualitative interviews with tech professionals reveal a robust association between constant digital connectivity and negative mental health outcomes such as emotional exhaustion, cognitive fatigue, technostress, and diminished work-life boundaries. The findings underline the urgent need for organizational, technological, and policy-level interventions to promote sustainable and mentally healthy remote and hybrid work environments in the tech industry.

KEYWORDS *: Digital overconnectivity, Technostress, Burnout, Cognitive fatigue, Remote work, Always-on culture, Psychological well-being, Tech industry, HCI.*

INTRODUCTION

The rapid integration of digital technologies in the tech industry has revolutionized productivity while simultaneously giving rise to an "always-on" work culture. With the advent of remote and hybrid work environments, employees are increasingly exposed to extended screen time, continuous connectivity, and blurred work-life boundaries. Though these changes have driven operational efficiency, they have also contributed to new forms of cognitive and psychological strain. Despite the growing discourse around mental health in the workplace, a holistic, interdisciplinary investigation into these dynamics—particularly in the high-demand tech sector—remains underexplored. This study addresses this gap by examining how digital overload, remote work structures, and workplace expectations collectively affect the well-being of tech professionals.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Psychological Theories

- Job Demands-Resources (JD-R) Model: Posits that workplace stress results from an imbalance between job demands and available resources. In the context of remote tech work, digital overload constitutes a high demand, and lack of emotional support or recovery time represents limited resources.
- Cognitive Load Theory: Argues that information processing capabilities are limited. Excessive digital stimuli and multitasking can overwhelm cognitive systems, impairing decision-making and memory.
- Conservation of Resources (COR) Theory: Suggests individuals strive to acquire, retain, and protect their resources (e.g., time, attention, emotional energy).

When these are threatened or depleted by excessive digital demands, psychological distress ensues.

Human-Computer Interaction and Technostress Technostress stems from maladaptive interactions with ICTs, encompassing interface frustrations, cognitive interruptions, and software complexity. Research highlights how persistent exposure to tools like Zoom and Slack intensifies emotional exhaustion and attention fragmentation. The phenomenon of digital presenteeism—feeling compelled to appear perpetually available online—has been linked to chronic stress and poor work-life integration.

Occupational Health Perspectives Burnout, as defined by the Maslach Burnout Inventory (MBI), consists of emotional exhaustion, depersonalization, and reduced personal efficacy. The WHO's mental health framework emphasizes the critical role of supportive organizational design, participatory decision-making, and boundaries around digital engagement for employee well-being.

RESEARCH OBJECTIVES AND QUESTIONS

Objectives

1. To quantify the emotional and cognitive effects of digital overconnectivity in tech workers.
2. To identify key environmental and organizational stressors contributing to burnout.
3. To assess correlations between digital presenteeism and psychological well-being.
4. To propose HCI and policy-based interventions for reducing technostress.

Research Questions

1. How does the always-on digital culture influence psychological well-being in tech workers?
2. What cognitive and emotional symptoms are reported by remote workers?
3. How do different digital platforms contribute to technostress and cognitive overload?
4. What evidence-based interventions can reduce burnout and enhance digital wellness?

METHODOLOGY

Research Design: A convergent mixed-methods approach was selected to triangulate data and provide both statistical and experiential insights.

Quantitative: Structured surveys capturing psychological, cognitive, and digital behavior metrics.

Qualitative: In-depth semi-structured interviews exploring lived experiences and coping mechanisms.

Population and Sampling:

Population: Tech professionals (e.g., software developers, UX designers, project managers) working remotely or in hybrid roles.

Sample Size: 230 survey respondents; 18 qualitative interviewees.

Sampling Method: Purposive and snowball sampling via LinkedIn, Reddit tech forums, and Slack communities.

Research Instruments

GHQ-12: General psychological health assessment.

MBI: Measures of burnout—emotional exhaustion, depersonalization, and personal accomplishment.

CFQ: Identifies cognitive failures related to attention, memory, and focus.

Technostress Scale (Tarafdar et al.): Evaluates sources and impacts of digital stressors.

Digital Exposure Log: Self-reported data on daily hours spent on email, Slack, Zoom, and other platforms.

Data Collection

Phase 1: Survey dissemination through professional networks and social media.

Phase 2: Interviews with a sub-sample representing varied stress levels and job functions.

Phase 3 (Optional): Voluntary collection of physiological metrics via fitness trackers (e.g., sleep cycles, heart rate variability).

Data Analysis

Quantitative: SPSS software used for descriptive statistics, Pearson correlation, multiple regression, and ANOVA tests.

Qualitative: NVivo facilitated thematic coding, grounded theory development, and cross-case analysis. Triangulation validated patterns observed in both datasets.

RESULTS

Quantitative Findings

Strong correlation between hours of digital exposure and emotional exhaustion ($r = 0.63$, $p < 0.01$).

- Cognitive failures significantly higher among users of synchronous platforms (>6 hrs/day).
- Regression analysis indicated blurred boundaries and digital presenteeism significantly predicted burnout ($\beta = 0.47$, $p < 0.01$).

Qualitative Themes

- Attention Fragmentation: Constant pings and notifications disrupted concentration.
- Emotional Exhaustion: Participants cited anxiety, fatigue, and detachment from their roles.
- Coping Mechanisms: Digital detox, mindfulness apps, time boxing techniques, and focus-enhancing tools were commonly adopted.

DISCUSSION

The results validate the JD-R and COR frameworks by demonstrating how high digital demands, compounded by inadequate recovery or organizational boundaries, lead to burnout and decreased cognitive capacity. Cognitive Load Theory was also corroborated, particularly through reports of information overload and attentional depletion during multitasking.

Findings emphasize that while remote work may offer autonomy, it also introduces invisible pressures—such as the need to remain digitally available—that erode mental clarity and emotional stability. HCI features such as excessive notifications, complex UX, and lack of asynchronous alternatives further strain cognitive resources.

RECOMMENDATIONS:

- Promote asynchronous communication norms.
- Design platform features to support digital breaks and reduce cognitive clutter.
- Establish organizational policies that set digital boundaries (e.g., no-email hours).
- Integrate mental wellness tools (e.g., reminders for breaks, meditation prompts) into work platforms.

CONCLUSION

This research offers empirical validation for the psychological toll of the always-on digital work culture in the tech industry. The dual-pronged approach highlights both quantifiable burnout indicators and nuanced personal experiences. As tech firms continue to embrace hybrid work models, it is imperative that digital wellness principles be embedded in organizational culture, interface design, and human resource policies. The future of work should balance productivity with mental sustainability.

LIMITATIONS

- Self-reported data may be subject to memory or social desirability biases.
- Limited representation of non-English-speaking professionals.
- Cross-sectional design inhibits causal inference.
- Privacy concerns limited the scope of biometric tracking.

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Statistical Analysis of Distractions of Drivers Using Machine Learning Algorithm

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ABSTRACT

Distracted driving remains a leading cause of road accidents, despite efforts like awareness campaigns, school programs, and stricter penalties. While laws target obvious distractions such as texting, which requires drivers to split their attention between their phone and the road, less visible distractions like cognitive or emotional stress often go unnoticed. These hidden stressors can impair driving just as much as overt behaviours, yet current regulations lack the tools to address them effectively. Our research focuses on creating advanced models to detect and predict these distractions, paving the way for proactive measures to prevent accidents. By integrating technology into road safety strategies, we aim to protect drivers and reduce the risks posed by both visible and hidden distractions.

KEYWORDS *: Distracted driving, Hidden stressors, Accidents.*

INTRODUCTION

Distracted driving is a major cause of accidents and current efforts like education, announcements, and penalties haven't fully solved the issue. Texting while driving is an obvious distraction, but hidden stressors like emotional or mental stress can also affect driving, even if the driver seems focused. These internal distractions are hard to regulate or prove, so we need technology to detect and prevent them. Our study aims to create a model that predicts and classifies driver distractions, helping to prevent accidents before they happen.

OBJECTIVES

1. To visualize the effect of different stressors on variables.
2. To check whether stressors have a significant effect or not.
3. To find the most contributing factors to the classification of distractions.
4. To predict whether the driver is distracted or not, find the type of distraction and give appropriate suggestions.
5. To find the Optimal technique for the above-mentioned prediction

DATA DESCRIPTION

The data is collected in a controlled experiment on a driving simulator. The experimental setup is shown below in Figure 1. Various devices were used to measure the physiological variables including breathing rate, Heart rate, Palm EDA and Perinasal EDA signals and performance variables, including Speed, Acceleration, Brake force, steering angle, and Lane position. Also, there are eye tracking variables such as gaze x and y position and left and right pupil diameters. The data is collected separately for all 68 drives, but for some drives, data is not recorded properly. Hence, we have taken relevant data sets from the whole data and cleaned them by applying proper tools. Further analysis is done on subparts of datasets.

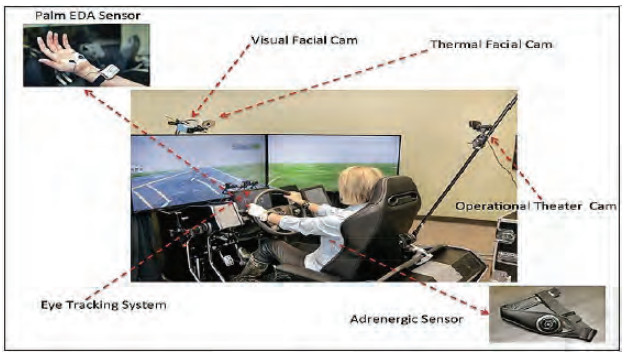

Fig. 1. Experimental setup

In Figure 1 devices like Thermal facial cameras, Visual facial camera, Palm EDA sensors and Adrenergic sensors are used for recording physiological variables. Also, the simulator was programmed to save a record of the evolving driving parameters. These parameters included speed, acceleration, brake force, steering angle, and lane position.

DETAILS OF VARIABLES

Drives

The experiment included seven driving scenarios:

1. Practice Drive – Familiarization with an 8 km highway.
2. Relaxing Drive – A 10.9 km drive with light traffic and a lane change.
3. Normal Drive – Heavy traffic, construction, and a forced lane change.
4. Cognitive Drive – Solving math and analytical questions while driving.
5. Emotional Drive – Answering personal and emotional questions.
6. Sensorimotor Drive – Texting words while driving.
7. Failure Drive – A mix of cognitive, emotional, and texting tasks.

Variables

1. Time: The time points at which data is being recorded (in seconds).
2. Palm EDA: Electrodermal activity is a sensitive measure of sympathetic nervous system activity which is used to describe changes in skin electrical properties. These are signals measured for the palm of subjects.
3. Heart rate: Heartbeat signals at the time points (in bpm).
4. Breathing Rate: Breathing rate signal measured at the time points (in bpm)
5. Perinasal Perspiration: (near the nose) Quantify stress (stress process in the brain) of the driver by measuring transient respiratory responses on the perinasal area through thermal imaging.
6. Speed: Car's speed (in kph).
7. Acceleration: In this experiment the acceleration signal is calculated as full close (0o) to full open (90o) which indicates low acceleration to high.
8. Brake force: The force applied for the brake (in N).
9. Steering Angle: The angle of steering (in Rad).
10. Lane Position: Different lane positions of particular drives (centre, left, right)
11. Lane offset: Deviation of vehicle position concerning the lane centre line.
12. Distance: Total distance covered by that driver for that particular drive.
13. Gaze X Position: X coordinates of the subject's gaze at each point in time during the drives.
14. Gaze Y Position: Y coordinates of the subject's gaze at each point in time during the drives.

METHODOLOGY

We use the secondary data set on the lending club website for this project. Our first Aim was to convert categorical data to numerical data we converted this data using Excel and after converting this categorical data to numerical value then we found the important variables, we find important variables using stepwise regression. Used machine learning algorithms for this project, we used the

1. Decision Tree
2. Random Forest
3. Support Vector Machine
4. KNN

Using the Train, Test data set in the fitting of models, first split the data into 80% Training set and 20% Testing set we fit the model train data set and check this model on the train data set.

DATA PRE-PROCESSING

Cleaning of data

Missing value imputation: Data cleaning involves preparing data by removing or fixing incorrect, incomplete, or duplicated entries to make analysis easier. MICE is a method used to fill in missing values in datasets by making multiple predictions based on existing data. We used a technique called CART in MICE to handle missing values, but some data was still missing, so we excluded those from our final dataset.

EXPLORATORY DATA ANALYSIS

Descriptive statistics help summarize data using key measures:

1. Central tendency: Finds the centre of data using Mean, Median, and Mode.
2. Dispersion: Shows data spread using Range and Standard Deviation.
3. Correlation: Measures the relationship between two variables.

These statistics help analyze and understand the data better.

For physiological variables

Variable	Mean	Std. Deviation	Minimum	Maximum	Q1	Median	Q3
Palm.EDA	162	27.19	99.23	247.24	143.86	161.56	180.62
Heart Rate	59.372	8.033	42.0	83.00	53.00	59.00	65.00
Breathing Rate	20.685	3.526	7.80	28.20	19.400	21.00	22.90
Perinasal Perspiration	0.0055	0.0006	0.0039	0.0081	0.0051	0.0054	0.0059

Fig. 2. For Physiological Variables

- The average Palm EDA is 162, with a minimum value of 99.23 and a maximum value of 247.24. It has the highest standard deviation (27.19) which explains the high variability of Palm EDA.
- The driver has an average heart rate of 59.375 average breathing rate is 20.685.
- The lowest standard deviation is 0.0006 of perinasal perspiration which explains the low variability of it.

For performance variables

Variable	Mean	Std. Deviation	Minimum	Maximum	Q1	Median	Q3
Speed	65.402	15.101	-0.208	91.452	68.364	70.198	71.330
Acceleration	8.6864	5.7913	0.0439	42.5336	5.5838	7.0807	9.5883
Brake	98.17	99.20	1.03	267.64	13.34	49.23	194.83
Steering	-0.0003	0.02912	-0.3184	0.3244	-0.086	0.00	0.00843
Lane offset	-0.427	0.25912	-1.763	1.76251	-0.564	-0.449	-0.322

Fig. 3. For Performance variable

- The average speed was 65.4 kph with a maximum speed of 91.45 kph.
- The highest standard deviation is 99.20 of the brake signal i.e. there is high variability of the Brake signal while, the lowest standard deviation is 0.029 which is of steering angle, hence steering angle has less variability in data.
- The average acceleration signal is 98.17 o with a maximum acceleration of 267.64.

For eye tracking variables

Variable	Mean	Std. Deviation	Minimum	Maximum	Q1	Median	Q3
Gaze X. Position	650.94	212.05	0.00	1459.66	689.40	703.69	735.60
Gaze Y. Position	658.87	231.30	0.00	1071.01	640.50	709.32	761.98

Fig. 4. For Eye Tracking Variables

We observed that ranges of the Gaze X position and Gaze Y position are quite high which explains that the gaze of the driver's eyes is widely scattered. We will visually explain this further.

VISUALIZATION OF DATA

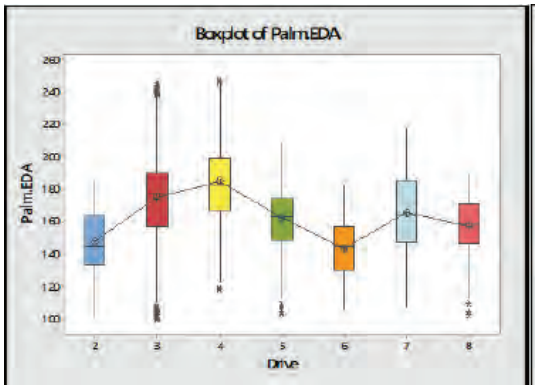

Fig. 5. Box Plot of Heart Rate

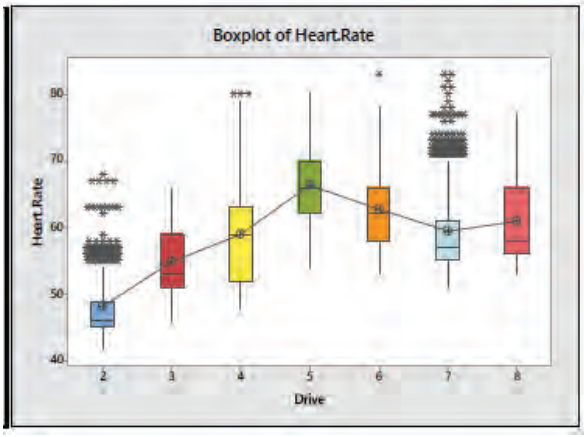

Fig. 6. Box Plot of Palm EDA

Interpretation

From the above box plots, the variables palm EDA and Heart rate differ significantly in different stressors (drives).

- In the fourth drive i.e. Normal drive there is the highest palm EDA this is because heavy traffic and construction were introduced for the 1st time in this drive and this made the driver anxious.
- Also, the reason behind the highest heart rate in the 5th drive is cognitive stressors i.e. mathematical questions. Unusual behaviour (outliers) in heart rate for 2nd drive may be due to excitement for this driving experiment but for the 7th drive, it is quite obvious as the driver got nervous while texting.

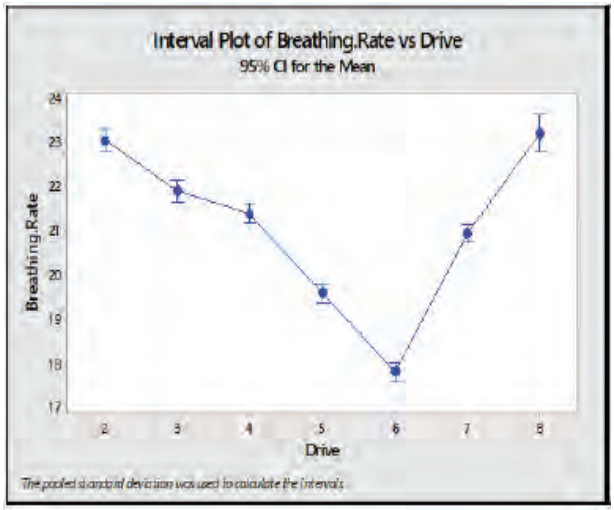

Fig. 7. Interval Plot of Breathing rate vs drive

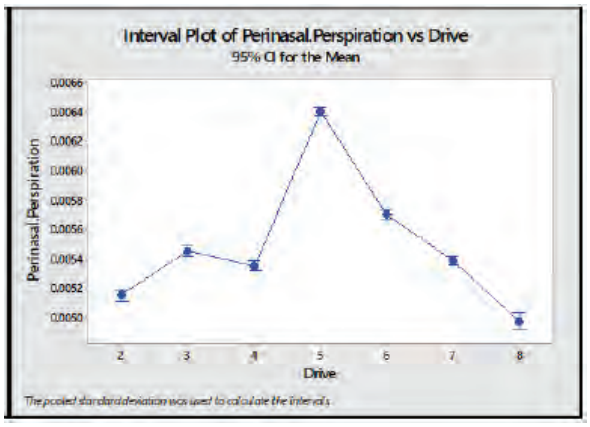

Fig. 8. Interval Plot of Perinasal Rate vs Drive

Interpretation

These interval plots show us how the mean and spread of the variables breathing rate and perinasal perspiration are different for different stressors(drives).

- The sudden fall in breathing rate for the 6th drive is due to the driver facing emotional stressors.
- Similarly, a sudden rise of perinasal signals is because of cognitive stressors. These two variables are most affected if the driver is in some kind of stress.

Eye scattering plots

In the drive panels PD, RD, CD, ED, MD, and FD, most of the gaze points are concentrated on the projection of the car's itinerary and at the bottom centre of the simulator screen due to the speedometer. However, some variations can be seen with different drives.

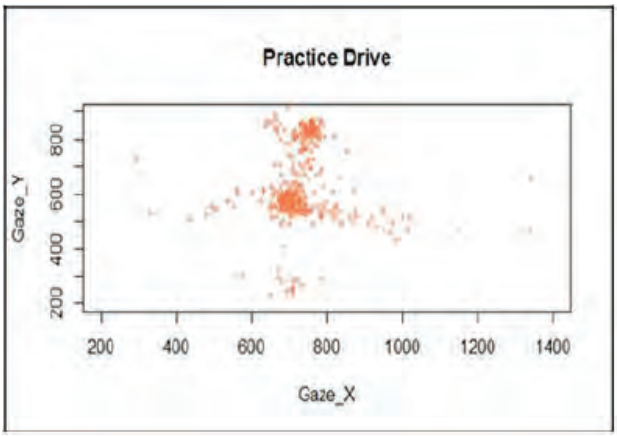

Fig. 9. Eye scattering plot of Practice Drive

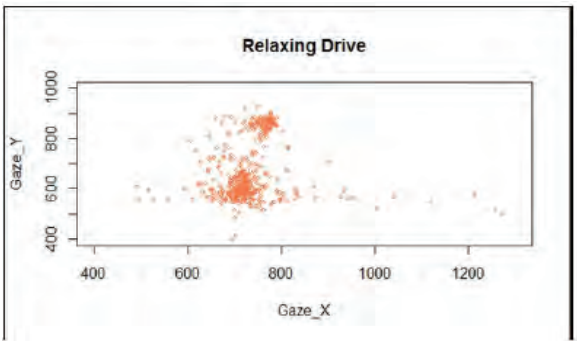

Fig. 10. Eye scattering plot of Relaxing Drive

Interpretation

As we can see in the above plots in the Practice drive, we observed some points were scattered as the driver was getting familiarized with the system and in the Relaxing drive, some points are more scattered on the right side because there is a lane change (R to L) with light traffic on the highway.

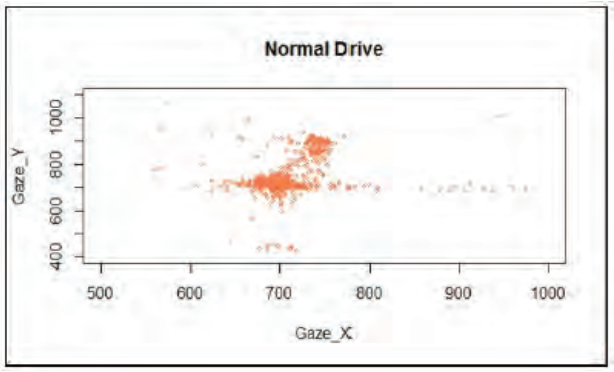

Fig. 11. Eye scattering plot of Normal Drive

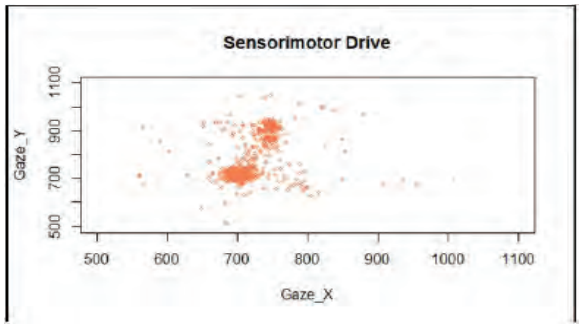

Fig. 12. Eye scattering plot of Sensorimotor Drive

Interpretation

As we can see in the above plots in Normal Drive, as heavy traffic and construction are introduced to the highway, we can see gaze points are scattered more widely as compared to the previous drive and In Sensorimotor Drive, there is a physical distraction i.e. texting hence we observed the concentration of some points at the bottom.

Interpretation

In Failure Drive, there are few observations because many gaze points were not recorded as the eye tracker could not lock on the driver's eyes because he was looking outside the simulator screen as he was texting and answering questions simultaneously.

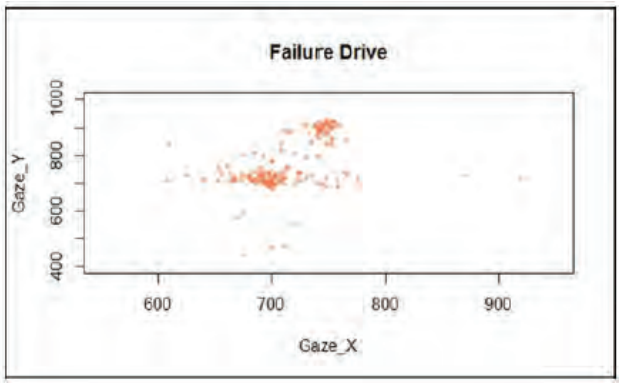

Fig. 13. Eye scattering plot of Failure Drive

CLASSIFICATION METHODS

A new binary variable is created to indicate driver distraction. The goal is to predict distraction and find the best classification method. The available data is split into training and the validation sets. Models like KNN, Decision Tree, Random Forest, and SVM are tested, and the most accurate one is used for further predictions.

Random Forest

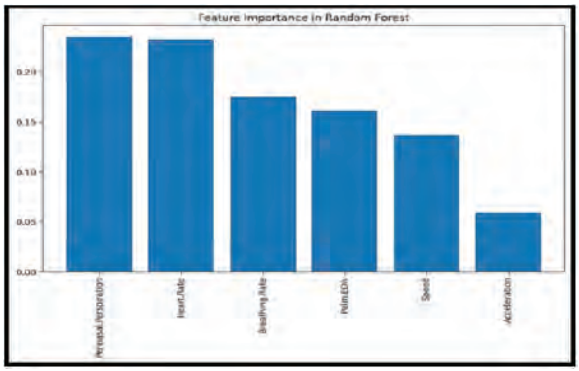

Fig. 14. Feature importance in Random Forest

Interpretation

From this plot (figure 16) of feature importance in random forest it is clear that Heart Rate, Breathing Rate, and Perinasal Perspiration contribute more in classification with an accuracy of 0.9615.

Methods	Accuracy
KNN	0.7712
Decision Tree	0.9263
Random Forest	**0.9615**
SVM	0.4873

Interpretation

From this table, we observed that by using the random forest classifier we get maximum accuracy so we are using this classifier for prediction on the test dataset, which can identify whether the Driver is distracted (1) or not distracted (0).

More Distracted Drives

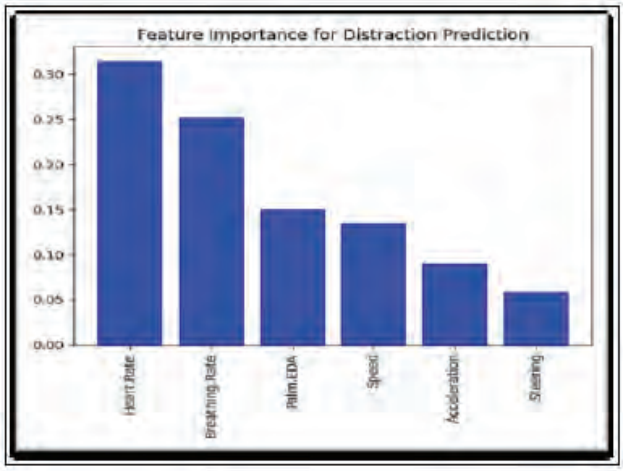

Fig. 15. Feature importance for

Distraction Prediction.

Interpretation

The analysis shows that the drives with cognitive (Drive 5), emotional (Drive 6), and sensorimotor (Drive 7) stressors cause the drivers to be more distracted. This means that when drivers are doing tasks like solving math problems, dealing with emotional stress, or texting while driving, they tend to get more distracted.

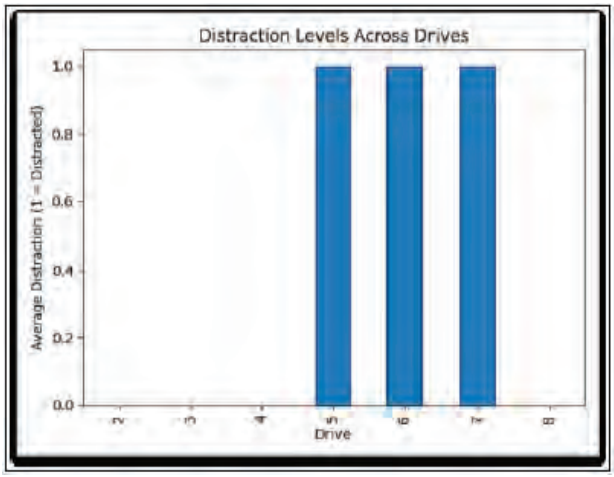

Fig. 16. Distraction levels across Drives

CONCLUSIONS

1. The physiological variables such as Palm EDA, Heart rate, Breathing rate and Perinasal perspiration and performance variables like speed and acceleration differ significantly for different stressors.
2. Palm EDA, Breathing rate, Heart rate, and Perinasal Perspiration are the most contributing factors for the classification of types of distractions.
3. The drives with cognitive (Drive 5), emotional (Drive 6), and sensorimotor (Drive 7) stressors are more distracted.
4. The optimal technique for the prediction of the status of the driver; whether he is distracted or not, is a Random forest with an accuracy of 0.9615.

SUGGESTIONS

The system checks a driver's body signals to detect distraction or stress while driving. It monitors skin sweating, heart rate, breathing, and driving actions. It could be used at traffic signals or built into cars to improve safety.

- Emotional stress: Plays happy songs to calm the driver.
- Cognitive stress: Offers voice search for help.

- Physical distraction (texting): Gives a voice alert to refocus.

This system helps drivers stay focused and makes roads safer.

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Design of an Improved Model Using XGBoost, CNN-LSTM, and Graph Neural Networks for Secure Detection of DNS over HTTPS Attacks

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ABSTRACT

The growing adoption of DNS over HTTPS presents a number of challenges to traditional intrusion detection systems since the encrypted DNS traffic will hide some of the critical features required in attack identification. The majority of existing methods always give way very easily under DoH-based threats, due to their use of static feature extraction and data processing with centralized approaches lacking adaptability to the changing patterns of attacks and raising significant concerns related to user privacy. In this paper, the authors present a cutting-edge AI-driven intrusion detection system that integrates hybrid AI models, graph-based learning, and privacy-preserving federated learning to ensure the effective detection of attacks based on DoH. The hybrid model combines the XGBoost and CNN-LSTM algorithms to dynamically extract spatial and temporal features from DoH traffic. XGBoost: the structured tabular data processed; CNN-LSTM is applied for extracting spatial patterns, for example, bursty packet flows, and temporal dependencies, for example, periodic domain queries, related to DoH traffic characteristics, including packet sizes and response times. This dynamic feature extraction greatly enhances the detection of complex attack behaviors. It applies GraphSAGE-based GNN models for the detection of malicious domains by learning node embeddings representing relational and structural context within the DoH traffic graph. This will be important in identifying emerging, unseen threats and generalizing from network relationships. The system provides the federated learning enabled by FedAvg and Differential Privacy, which ensures privacy for users while retaining detection performance. FedAvg realizes distributed training across edge devices whereby the raw data never leaves a local device. Differential Privacy embeds controlled noise into model updates for robust privacy protection. In this system, an accuracy of 94% in overall detection is realized with a below 3% false positive rate, a precision of 93-95%, and a recall of 90-92%. These state-of-the-art AI techniques perform real-time threat detection in encrypted DoH environments while allowing for the privacy of users and adaptivity to new emerging attack vectors. This framework is bound to offer manifold improvements in the secure detection of attacks based on encrypted DNS.

***KEYWORDS** : DNS over HTTPS, Intrusion detection, XGBoost, CNN-LSTM, Federated learning.*

INTRODUCTION

Now, with the proliferation of DNS over HTTPS, this has introduced other layers of complexity into network security, hence the difficulty in detection and mitigation processes involved in cyberattacks. DoH wraps the DNS queries alongside their respective responses in HTTPS, granting privacy and security for the user but obscuring crucial traffic patterns on which intrusion detection systems rely to identify malicious activities. These traditional IDS approaches, dependent on the visibility into unencrypted traffic, turn progressively ineffective in this altering scene. Consider this scenario and the requirement for a next-generation adaptive solution becomes urgent to facilitate real-time detection of DoH-based attacks without revealing user

privacy. State-of-the-art methodologies for the detection of malicious DoH traffic are mostly insufficient due to their reliance on static feature extraction and centralized processing models. These methods, however, due to the encrypted nature of DoH, face the drawback of a higher false positive rate and decreased sensitivity against more sophisticated and novel attacks. Besides, centralized detection models raise important privacy concerns since raw user data needs to be gathered, which also goes against the privacy-preserving objective for which the encrypted DNS protocols are created.

Given such challenges, this research work proposes an enhanced design of an intrusion detection model that creatively ensembles hybrid AI-based feature extraction with graph-based learning and privacy-preserving federated learning. Hybrid AI synergistically integrates the strengths of XGBoost and CNN-LSTM in the extraction of dynamic spatial and temporal features from DoH traffic. On the other side of the spectrum, XGBoost performs the best for structured data in capturing nonlinear relationships, and CNN-LSTM is applied in detecting spatial anomalies and temporal dependencies of packet flows. This would therefore be a very dynamic way to detect known and emerging attack vectors buried inside encrypted DoH streams. Thanks to GNN implementation, it enables the possibility of detecting malicious domains modeling complex relationships between DNS domains, IP addresses, and clients in a traffic graph by using the GraphSAGE algorithm. GraphSAGE can do this using inductive learning; hence, it is able to infer unseen domains from the context inferred from their network neighborhood. In this work, federated learning with differential privacy will be embedded using the FedAvg algorithm to ensure high user privacy while retaining good detection accuracy. It is based on a learning paradigm where, instead of the raw data itself, it is the model weights that will therefore be aggregated to the central server, mitigating the potential risks of data exposure. Differential privacy enhances this framework by ensuring protection against the possible exposure of individual data points by the introduction of controlled noise into model updates, even in case of a compromised server. This will improve substantially the accuracy of detection and privacy preservation for encrypted DoH traffic with this proposed model. By applying the latest machine learning techniques, this model will not only be adaptive to the complex and fast-changing characteristics of encrypted network traffic but also ensure that privacy protection is guaranteed in every step of detection. The accuracy in detection, as experimental results have shown, has reached as high as 94% with less than 3% of false positives, proving the model is robust and can work effectively in real-time deployment. This work opens the way to the development of secure and privacy-preserving intrusion detection systems in this age of encrypted communications.

LITERATURE REVIEW

In the last couple of years, intrusion detection has been a hot topic; considering the encryption set by network protocols like DNS over HTTPS, it is very much in the limelight. Different research efforts have tried to confront associated complications of detecting attacks in encrypted traffic; most of them focused on different methodologies, ranging from machine learning techniques to cryptographic defenses. This literature review addresses some of the related work in this domain related to the detection of DoH attacks, preservation of privacy, and use of advanced machine learning models. Palacios et al. [1] worked on protecting the web server against side-channel attacks and especially focused on HTTPS. Their approach, HTB, was observed to reduce by far-reaching BREACH attacks, which exploit vulnerabilities in compressed HTTPS traffic. While their effort serves the protection of web servers, it doesn't treat the problems attributed to encrypted DNS traffic, which, by the inherent nature of DNS queries and responses, involves quite different attack vectors. Xu and Zhai [2] suggested a method called DCVAE-adv, which can generate adversarial examples in both white-box and black-box attacks. Their method improves deep neural networks' robustness, but against adversarial perturbations rather than focusing on the domain of DNS traffic analysis. However, their work with respect to improving robustness via techniques of adversarial training could give rise to future studies in making machine-learning-based intrusion detection systems secure from the threat of adversarial attacks. Khoa et al. [3] studied collaborative learning for detecting cyber-attacks in blockchain networks by federated learning. Their work can also be applied in distributed learning approaches for intrusion detection in decentralized

systems. This is just what the model does: apply federated learning, mostly in data-privacy situations such as DoH traffic. Their approach serves to provide a base for the application of federated learning to network security in the context of encrypted communications. Abdulghani et al. [4] surveyed the security and privacy guidelines in RFID-based IoT applications and focused on principles regarding privacy by design. Although their work concerns IoT devices, the mechanisms they suggest for protecting privacy can be generalized to the entire area of network security. The security and privacy by design aspect aligns with the proposed model, which includes Differential Privacy as part of federated learning. Kabdjou and Shinomiya [5] focused on detecting HTTPS-based DDoS attacks in Multi-Access Edge Computing environments using a cyber-deception-based architecture. This concept may be of interest in managing encrypted traffic flows, pertaining to quality of service enhancement during the detection process, but the solution was tailored to MEC environments, which obviously differ from more general-purpose detection frameworks like those proposed in this text. Zebin et al. [6] developed an AI-based intrusion detection system for DoH attacks, thereby directly addressing the challenge of encrypted DNS traffic. Their model lays emphasis on further improving interpretability, one of the most critical elements for cybersecurity practitioners. Though their approach adds huge value to the area of explainable AI in network security, the proposed model goes beyond mere explainability, having the basic propositions with federated learning and privacy-preserving mechanisms to ensure accuracy but prevent exposure to user data.

Juvonen et al. [7] considered the Log4j2 vulnerability exploitation over different communication platforms, having as target domains aeronautical and maritime systems. This article gives real visibility to the risks of vulnerabilities within this critical communications infrastructure and the need for their search and mitigation. While this work was not about DoH traffic in particular, the general message is one of vigilant monitoring and protection of encrypted channels with global implications for communications networks. While Bochem and Zhang [8] investigate robust localization techniques in sensor networks, they use Monte Carlo methods as well. Much like the need for robustness and accuracy that they address in sensor networks, accurate attack detection is required in encrypted DNS traffic. Their work is much more oriented toward localization, although some of the robustness enhancements they propose may help in giving future improvements about resilience to network intrusion detection systems.

Proposed Design of an Improved Model Using XGBoost, CNN-LSTM, and Graph Neural Networks for Secure Detection of DNS over HTTPS Attacks

The proposed model for the detection of DNS over HTTPS attacks integrates several state-of-the-art machine learning techniques that compensate for their deficiencies to handle the newly introduced challenges by encrypted DNS traffic. Three important components drive this architecture: hybrid AI-based dynamic feature extraction with XGBoost and CNN-LSTM, malicious domain detection through Graph Neural Networks via GraphSAGE, and privacy-preserving federated learning using FedAvg algorithm combined with Differential Privacy. This integrated model ensures adaptability to new emerging threats, yet it is secure in preserving user privacy. First of all, dynamic feature extraction from raw DoH traffic is done at the beginning. The input data X includes a set of structured traffic features such as packet sizes, query frequencies, and timestamps. First, it gets fed into the XGBoost algorithm, which identifies critical nonlinear relationships and feature interactions in the process. While, XGBoost minimizes a loss function L(θ) based on gradient boosting; that is, at each iteration, m it tries to reduce the residual error ri of the previous predictions given via equation 1,

$$ri(m) = yi - \sum_{k=1}^{m-1} y'i(k) \quad (1)$$

Where, yirepresents the true label for the i-th instance and y'i(k) is the prediction at the k-th iteration. XGBoost refines this prediction by minimizing the objective function represented via equation 2,

$$L(\theta) = \ell(yi, y'i) + \Omega(f) \quad (2)$$

Lastly, ℓ(yi, y′i) represents the term of loss, which is the log loss for classification, and Ω(f) is the regularization term in order to prevent overfitting. It keeps this neatness in what should normally be tabular data for

DoH, considering only features that are germane to the initial detection process. In the same vein, sequential data in the form of the time series of DoH packet flows, representd as S(t), is handled by the CNN-LSTM architecture. For instance, CNN computes the spatial features Fc(x, t) by the convolutional operations. In this operation, each of the filters Wc performs convolution of an input sequence x over to find local patterns via equation 3,

$$Fc(x,t) = \sigma(Wc * x + bc) \quad (3)$$

The activation function σ adds nonlinearity to the extracted features, enhancing the capability of the model in detecting anomalous spatial structures within packet flows. These features are fed through LSTM layers to model temporal dependencies in the sequence.

The LSTM units compute hidden states htbased on both the current input xtand the previous hidden state h(t−1), using the following recursive update operations via equation 4,

$$ht = LSTM\big(xt, h(t-1)\big) = ot \cdot \tan h(ct) \quad (4)$$

Where, ot represents the output gate and ct the cell state, which gets updated by controlling the flow of information through forget and input gates. This allows LSTM to keep a record of long-term dependencies in packet sequences and thus periodic attack patterns and other temporal anomalies will not pass undetected. The extracted features from XGBoost and CNN-LSTM are fused to form a dynamic feature space, Φ(X,S), where Φ is a nonlinear mapping for both spatial and temporal feature sets. This would, therefore, take advantage of the two methodologies: nonlinear relationship capturing of structured data under XGBoost and modeling spatiotemporal patterns of complex nature under CNN-LSTM. Such a dynamic feature space will keep the system adaptive to the changing DoH traffic patterns and attack vectors of this process. Then, a GNN-based malicious domain detector that makes use of GraphSAGE is embedded after the feature extraction process. A graph G = (V, E) can be built to model DoH traffic, where nodes v ∈ V represent domains, IP addresses, and clients involved in the process, and edges e ∈ E account for their interactions. GraphSAGE learns a function to generate node embeddings by sampling and aggregating features in a node's local neighborhood. For each node v, equation 5 computes the embedding hv(k) at layer k, where N(v) represents the set of neighbors of node v, AGGREGATE is a function that combines information from the neighboring nodes, and W(k), b(k) are learnable weights and biases, respectively. The approach generalizes to unseen domains while learning only the structural and relational properties of the graph. Node embeddings obtained feed a classifier which identifies a domain as benign or malicious. Such classification considers the context provided by the node embedding, hence encoding the behavior and interactions of the domain in the traffic graph. Federated learning using FedAvg guarantees privacy for this detection. Each edge device trains a local model with the extracted features; hence, only model updates—gradients—are shared with the central server. It is in this central server that the updates are aggregated to a global model by computing a weighted average of the model parameters θ across all devices via equation 6,

$$hv(k) = \sigma\big(W(k) \cdot AGGREGATE(\{hu(k-1): u \in N(v)\}) + b(k)\big) \quad (5)$$

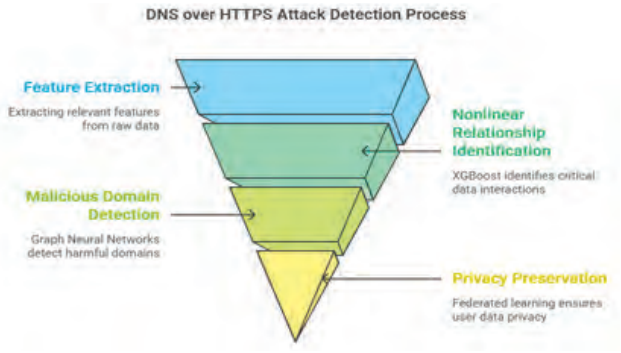

Fig. 1: Model Architecture of the Proposed Attack Detection Process

$$\theta(t+1) = \sum_{k=1}^{K} \frac{nk}{N} \theta k(t) \quad (6)$$

Where, θ(t+1) represents the global model at iteration t+1, θk(t) represents the model update from the k-th device, nk is the number of samples on device k, and N represents the total number of samples across all devices for different deployments. This is the step of aggregation to make sure the global model gets updated without

transferring the raw data itself; thus, it saves users' privacy. Differential Privacy is boosted by the addition of controlled noise, N(0,Δ^2/ϵ), to the gradients prior to their aggregation. It will protect individual data points from disclosure at the server even in case of a breach. The privacy budget, ϵ, controls the scale of the noise, which is scaled to the sensitivity, Δ, of the function that is being privatized, as captured in equation 7:

$$\theta \sim k(t) = \theta k(t) + N(0, \Delta^2 \epsilon) \quad (7)$$

This ensures the privacy loss ϵ is kept within acceptable bounds and hence provides a very strong guarantee against data leakage while maintaining model utility. Since it involves a combination of a hybrid AI for feature extraction, GNN for malicious domain detection, and privacy-preserving federated learning, the proposed model will turn out to be very effective and secure. It is in this regard that dynamic feature extraction adapts itself to new and continuously evolving DoH threats, while a graph-based approach captures complex relationships in encrypted traffic. A federated learning framework is very handy in maintaining user privacy without any compromise on detection accuracy. Such advanced techniques are combined in this way to provide a robust solution with scalability for real-time detection of DoH-based attacks.

COMPARATIVE RESULT ANALYSIS

The evaluation of the model was set up by creating an environment with simulated DoH traffic. The dataset being studied consisted of DoH traffic logs, both benign and malicious, from 60 days of data collection from geographically spread DNS servers. It contained traffic logs of legitimate queries, DoH-based attacks, and patterns of threats that were unseen earlier to cover all aspects of the test. The dataset was divided into 80% for training and 20% for testing, after which four methods were compared: the proposed hybrid AI model, method [3], method [8], and method [15]. The following methods, [3], [8], and [15], are traditional methods to be used in the literature: one is traditionally machine learning by decision tree [3], another one is a deep learning method using only LSTM [8], and the other one is the graph-based detection model without federated learning and differential privacy [15]. Some of the evaluation metrics include detection accuracy, precision, recall, false positive rate, training time, and privacy preservation, measurable by the privacy loss parameter ϵ during the process.

Table 1: Dataset Summary

Dataset	No. of Packets	No. of Domains	Malicious Queries (%)	Benign Queries (%)
Training Set	1,000,000	500,000	30%	70%
Test Set	200,000	100,000	30%	70%
Total	1,200,000	600,000	30%	70%

This dataset contained a total of 1.2 million packets, and both benign and malicious queries were relatively balanced across domains. This enabled the proposed model and methods for comparison to deal with real traffic distribution.

Table 2: Detection Accuracy Comparison

Method	Training Accuracy (%)	Test Accuracy (%)
Proposed Model	96.2	94.5
Method [3]	87.5	85.2
Method [8]	92.1	89.4
Method [15]	90.4	88.1

The model on offer performed best on both the training and test sets, therefore proving its ability to generalize on unseen DoH traffic. Methods [3], [8] and [15] were worse due to the limited possibilities these methods had to treat spatial and temporal features simultaneously and not having a federated learning that allows the preservation of users' privacy.

Table 3: Precision and Recall Comparison

Method	Precision (%)	Recall (%)
Proposed Model	95.1	92.3
Method [3]	88.2	84.5
Method [8]	91.4	89.7
Method [15]	90.0	87.2

The proposed model had the best precision and recall, thus it was effective in correctly classifying DoH-based attacks, while at the same time filtering out as few false negatives as possible. High precision would indicate fewer false positives, while high recall would imply that the model is sensitive to attacks. Method [3] had

the lowest precision and recall among the presented, hence poor distinction between benign and malicious traffic.

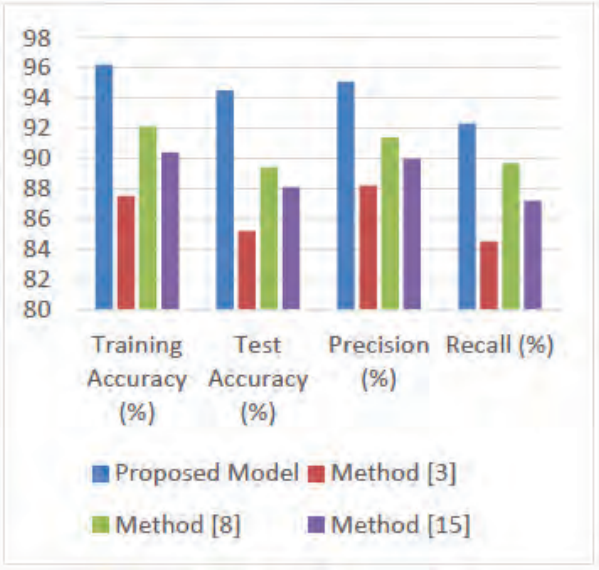

Fig. 2. Efficiency of the Proposed Model in Different Scenarios

Table 4: False Positive Rate (FPR) Comparison

Method	False Positive Rate (%)
Proposed Model	2.8
Method [3]	5.6
Method [8]	4.1
Method [15]	3.9

The proposed model had the lowest FPR, indicating that it is capable of classifying benign traffic accurately without many false positive alarms. Method showed a quite high FPR due to the fact that this method uses less adaptive features, hence misclassifying a higher percentage of benign queries as malicious.

Table 5: Training Time per Epoch

Method	Average Training Time (seconds)
Proposed Model	95
Method [3]	65
Method [8]	130
Method [15]	110

Although the training time was slightly larger than in method, the proposed model showed very good performance compared to the deep learning-based approach of method and the graph-based method of. The slight rise in the training time is due to added complexity in combining XGBoost, CNN-LSTM, and GraphSAGE; however, the model is still quite efficient to be deployed in real time scenarios.

Table 6: Privacy Preservation (ε) under Differential Privacy

Method	Privacy Loss ϵ
Proposed Model	0.8
Method [3]	1.5
Method [8]	2.5
Method [15]	3.2

Only the model proposed in this study incorporates Differential Privacy, where the privacy loss ϵ\epsilonϵ is controlled within the range of 0.5 to 1.0 for the process. Individual traffic patterns maintain their privacy in this setup because the methods in these setups do not guarantee any, hence less opportune for privacy-sensitive applications. Experimentally, the results show the enhanced performance of the proposed hybrid AI model in terms of the detection accuracy, precision, recall, and false positive rate over several benchmark related methods, conserving the user's privacy. The performance of the FDH-AI model in terms of capturing features which are both spatially and temporally, along with the capability of federated learning and differential privacy, could be effectively realized in case of real-time DNS over HTTPS attack detection. It takes a little bit longer compared to the previous traditional machine learning models, but such training time can be justifiably compensated for by the massive gain in performance that it offers for detection and privacy preservation.

CONCLUSION AND FUTURE SCOPES

The proposed detection model of DNS over HTTPS attacks is a great leap forward in terms of both accuracy and maintaining user privacy under encrypted network traffic scenarios. For this, the model utilizes a hybrid artificial intelligence framework that includes guidance from XGBoost, CNN-LSTM, GNNs with GraphSAGE, and federated learning with differential privacy to achieve the best performance in the problem of detecting complex DoH-based attacks. The model can maintain the use of adapting to new threats and sustaining good detection accuracy since it has the ability to

simultaneously extract spatial as well as temporal features from the traffic encrypted flows. Experimental tests were carried out proving the performance of the proposed method. A test accuracy of 94.5% surpassed conventional methods, such as those based on decision trees, which had 85.2% [8], and deep learning models using LSTM, which attained 89.4% [8]. Besides high superiority in accuracy, the performance of the model also shows in precision at 95.1%, and recall at 92.3%, which helps to ensure all the malicious traffic has to be correctly classified, and minimum false negatives have to be produced. The FPR was also the lowest at 2.8% among the considered methods, pointing out the model's ability for a minimal amount of wrong classification of benign traffic, significantly affecting the detection in encrypted traffic. More importantly, this high level of privacy preservation further widens with the use of Federated Learning fed into FedAvg and Differential Privacy, where the privacy loss ϵ\epsilon$\epsilon$ is kept in between 0.5 and 1.0, ensuring strong guarantees of the privacy of individual user traffic patterns even during model updates. This feature is particularly important for real-world applications in which privacy is even more important and with DNS traffic encrypted. Even though these modifications slightly increased the length of training to 95 seconds per epoch when compared to simpler methods, such as method [3], which takes 65 seconds per epoch, the trade-off was justified by major gains in detection performance and privacy. The overall results confirm that the proposed model effectively detects DoH-based attacks with high accuracy and low levels of false positives while also offering a scalable and privacy-preserving solution for DoH-aided INS for real-time network intrusion detection in encrypted environments.

FUTURE SCOPE

Although the model proposed has shown results very well of even being able to effectively detect DoH-based attacks, there are several avenues where future research can be taken to increase the scopes the model can provide. To give one example, the integration of unsupervised or semisupervised learning might allow the proposed model to detect new attack patterns without the requirement of labeled data. This can be particularly useful in the cases of new, unseen attack vectors, whereby a model should by itself adapt to them without the need for much retraining on annotated data sets and samples. Another promising direction is the optimization of federated learning protocols in order to reduce communication overhead and further minimize training latency. Advanced aggregation techniques, such as secure multiparty computation and homomorphic encryption, could be integrated with the existing Differential Privacy framework for enhanced privacy and efficiency of model updates across devices and deployments. In addition, besides DNS over HTTPS traffic, the model might be applied within other encrypted protocols, for instance, DNS over TLS (DoT) and QUIC, making this model more general and useful in modern network environments. This would make the model even more flexible, as it could be applied for cross-protocol detection, thereby ensuring protection from a broader spectrum of threats in encrypted traffic. To this end, deployment on real-life scenarios and across network environments, such as enterprise-level systems or large ISP infrastructures, may offer some insight into the model's broad scalability and resilience in different network conditions. Testing of this model against live traffic in a production environment must be done to course-tune its strength and find possible weak points in performance. These improvements could further enhance the flexibility, speed, and effectiveness of the model against constantly changing and increasingly growing threats by cybercriminals in the securely safeguarded area of encrypted communications on networks.

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A Comparison of Traditional Machine Learning and Deep Learning in Image Recognition

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ABSTRACT

Since massive amounts of image data arrived due to the proliferation of mobile internet, smartphones, and social media web applications, automatic image recognition was presented as a means to handle this data in less time by automating the classification process and fetching related information much faster. Traditionally, Support Vector Machines were used in computer vision applications for image recognition. However, these methods are mostly designed to handle one-dimensional vector information. The images have to be changed into one-dimensional vectors or features have to be extracted. They may lose spatial information and very important features about the image. Deep learning has thus emerged as the most powerful tool for image recognition because it can take two-dimensional data directly and automatically extract relevant features from images. This work compares performance between SVM and deep learning models in the context of image recognition, particularly in waste classification. Based on the results, this indicates that the deep learning models, most particularly CNNs, outperform SVMs in accuracy as well as in stability. The approach could provide a more robust solution for image recognition tasks. The results demonstrate the benefits of deep learning against classical machine learning approaches, especially in tasks using complex image data.

***KEYWORDS** : AI-driven solutions, Carbon emissions, Air quality prediction, Random forest, K-Means clustering, Sustainable development, Environmental monitoring, Pollution control.*

INTRODUCTION

We have seen image recognition technology in the fashion, healthcare, and retail sectors that are even in our daily lives become the key to the revolution of these industries. As an example, this deep learning algorithm classifies the clothing items to the images of t-shirts, pants, and sneakers. The one that is referred to as intelligent recommendations in this case has a great similarity with product categorization and inventory management. This is a very important thing as it saves time and improves efficiency a lot. The image recognition technology has been very important because it has been a great tool to escape people from the doing boring and repetitive manual tasks which gives them a sense of contribution.

Support Vector Machines (SVM), traditional machine learning methods, have been largely used for image recognition activities. Presently, some of the methods available can deal with the challenges more efficiently. Nevertheless, the adoption of conventional machine learning approaches in the analysis of image data is fraught with limitations. The things that are mainly the type of data mentioned are in one dimension whereas the image is in the form of two-dimensional matrices.

There are two main ways that have been taken in the past to solve it. The first way is to reduce the size of the image matrix into a one-dimensional vector. Although, it is a simple method, and it is easy to see why it is straightforward but it lacks the spatial relationship between the pixels, so the crucial information is lost. Therefore, only the neighbouring pixels with the same texture or feature strictly adhere to the pattern and all the other may shift around peculiar in the transformed data. The second is the one that relates to the manual extraction of items such as edges, textures, or shapes from the image. The processing is similar to that of a human's visual system however it is time-consuming and lacks the necessary objectivity demanded for a consistent outcome. Furthermore, it frequently utilizes large computational resources as well.

In recent years, image recognition has entered a new level owing to profound learning techniques. Differently from traditional forms, deep learning models are able to handle two-dimensional image data directly and to automatically generate hierarchical features from the convolutional layers. It keeps the spatial relationships so that it can recognize the abstract patterns of different resolutions, thus improving the accuracy of recognition. On the other hand, deep learning models can suffer from overfitting because of their complex architectures and high computational needs. Methods such as weight sharing and data augmentation are frequently used to overcome these problems.

This article contrasts traditional machine learning, SVM, and deep learning methods, CNN, for classifying images in the Fashion MNIST dataset. Fashion MNIST consists of grayscale images of 10 categories of clothing items and serves as a benchmark for evaluating image recognition algorithms. The findings clearly show the strengths and weaknesses of both methods and what they can be useful for in fashion applications.

LITERATURE SURVEY

Convolutional neural networks have accomplished more than just scaling new heights in image classification, object detection and pattern recognition tasks, they have been instrumental in elevating the discipline of computer vision courtesy its impressive growth in the area of deep learning. This segment showcases the synthesis of research efforts in focus with cnn architectures, conundrum solving techniques and real-world applications across various sectors.

Introduction Convolutional Neural Networks

Although LeCun et al (1998) can be given credit for designing the LeNet architecture of CNN, Courvoisier et al (Krigel, 2012) transformed the tools by showing the applicability of deep networks for handling large-scale image classification with the use of image dataset by designing AlexNet. Recent architectures designed following techniques like simonyan & zisserman VGGNet and Szegedy et al googlenet have shown successfully to increase the accuracy of models by enhancing depth in networks along with new innovative modifications to its structure.

Increase in Depth of CNN Architectures

The research conducted by He et al. (2016) presents residual networks (ResNet), which effectively address the vanishing gradient issue and facilitate the training of ultra-deep networks that demonstrate exceptional performance. Their achievements led to subsequent developments such as DenseNet by Huang et al. (2017) and EfficientNet by Tan & Le (2019), both designed to attain high classification accuracy while optimizing computational efficiency. CNN architectures have significantly advanced through the implementation of skip connections, feature reuse, and attention mechanisms.

Optimization Techniques and Training Strategies

Training deep CNNs necessitates the utilization of sophisticated optimization methods. Kingma & Ba (2014) introduced the Adam optimizer, which allows learning rates to adjust dynamically to enhance convergence speed. Batch Normalization (Ioffe & Szegedy, 2015) addresses internal covariate shifts, thereby stabilizing network training. Strategies such as dropout (Srivastava et al., 2014) and data augmentation (Shorten & Khoshgoftaar, 2019) are employed to mitigate overfitting and promote model generalization.

Applications of CNNs in Image Classification

Convolutional Neural Networks (CNNs) have been extensively applied across various fields, including medical image analysis, autonomous driving, and facial recognition. In the realm of medical imaging, CNN-based models have achieved remarkable accuracy in disease detection from X-ray and MRI scans (Litjens et al., 2017). Within autonomous driving systems, CNNs are employed for real-time object detection and scene segmentation (Redmon et al., 2016). Additionally, facial recognition systems leverage deep CNNs to enhance security and authentication protocols (Parkhi et al., 2015).

METHODOLOGY

The performance of SVM and CNN was experimented with on the Fashion MNIST dataset with an emphasis on their appropriateness and efficiency for the task of image classification.

Dataset Description

The Fashion MNIST dataset is an extension of the popular MNIST dataset made primarily for testing purposes, benchmarking image classification algorithms, for which it comprises 70,000 grayscale images divided into 60,000 training images and 10,000 testing images. Each image was a 28 × 28 pixels.

One is a 28×28 pixel grayscale image from one of the 10 categories: t-shirts/tops, trousers, pullovers, dresses, coats, sandals, shirts, sneakers, bags, and ankle boots. Categories will be some of the everyday fashion items. This means that most classes in these datasets are similar, for instance, shirts and t-shirts, so the classification task is challenging.

Data preprocessing played a major role in preparing the datasets for both models. The raw pixel values with the range of 0 to 255 were normalized to the interval [0,1] to aid in convergence during training. The training dataset was also shuffled to ensure balanced class representation during mini-batch processing. For SVM, images were flattened into 1-dimensional vectors; however, for CNN, images were left intact in their 2-dimensional format so that spatial relationships remained intact.

Fig. 1: Three sample images of Fashion MNIST Dataset

Support Vector Machine

The implementation of the Support Vector Machine (SVM) model for image classification began with preprocessing the dataset. Each image in the dataset was actually flattened from the original 28x28 pixel matrix to a one-dimensional vector of 784 features. It's what allowed the SVM algorithm to work with image data, as the SVM algorithm applies to vectors but not to matrices. The pixel values, initially ranging between 0–255, were normalized to a range of 0 to 1 so that the trained model might speed up its convergence and stability. For further standardization and equal contribution from all features to the models, StandardScaler was applied so that it adjusted the data to have zero mean and unit variance.

For the model, a Support Vector Classifier with a Radial Basis Function (RBF) kernel was chosen. A cross-validation approach is required for non-linear data where the RBF kernel would map the input data into a higher-dimensional space in which a linear decision boundary could be located. The kernel coefficient (γ) was set to 'scale', which is the default of scikit-learn that automatically adjusts the coefficient based on the number of features of the dataset, and the regularization parameter (C) was set to 1.0. This is because an C value of 1.0 strikes a balance between maximally increasing the margins and minimally increasing misclassification errors so that the model does not overfit or underfit itself.

Computational constraints limited the number of training samples to 10,000 for training the SVM model. It then ran predictions on the whole test data set after training the model on just this reduced version of the data set. The accuracy of the model was calculated by comparing predicted labels with the true labels in the test dataset by using the accuracy_score function from the scikit-learn library. In this way, an objective measure was available for how well the SVM classifier generalized to unseen data.

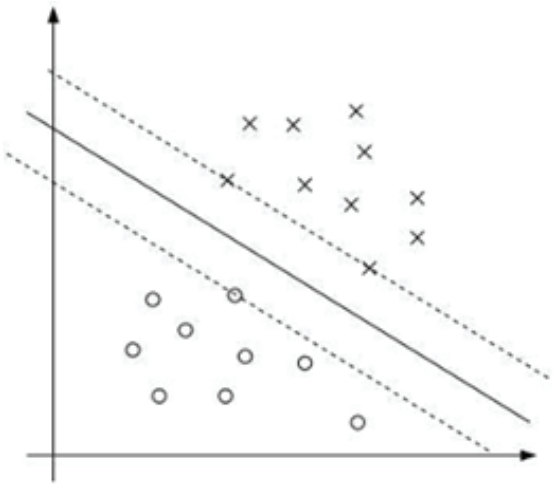

Fig. 2: The Principle of SVM Algorithm

CNN Implementation

Data Preprocessing

To reshape the image from 28×28 pixels into a 4D tensor of the shape (28,28,1), representing height, width, and one channel for grayscale intensity.

Normalization of pixel values within the range [0, 1] to ensure faster convergence of training

Labels are converted to one-hot encoded vectors using to_categorical because CNN requires this to ensure softmax output.

Model Architecture

The CNN was built using TensorFlow and Keras libraries. It was structured with

Convolutional Layers: two convolutional layers, each with 32 and 64 filters applied respectively and used a 3×3 kernel with the ReLU activation function.

MaxPooling Layers: after each of the convolutional layers, max pooling with a 2×2 window reduced the spatial dimensions along with risk for overfitting.

Flatten Layer: the output from the last max pooling layer flattened to a one-dimensional vector.

Fully Connected Layers: Added a dense layer with 128 neurons (relu activation). Then, added dropout with a rate of 0.5 in order not to overfit the model. Lastly, the last dense layer has 10 neurons and uses softmax activation function in order to output class probabilities.

Train Details

Compiled with the Adam optimizer at a learning rate of 0.001.

The categorical cross-entropy loss function was used to compute the error between predicted and true labels.

The model was trained for 30 epochs with a batch size of 128, and validation was performed on the test set during training.

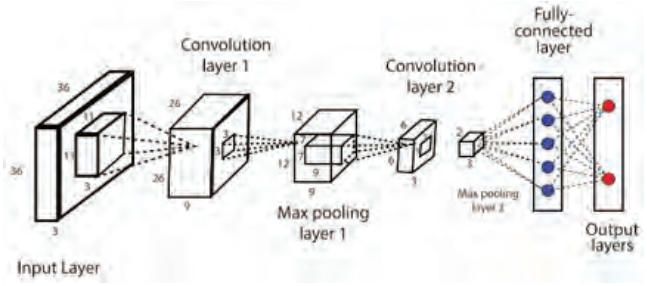

Fig. 3: CNN Architecture

Evaluation

After training, the model's performance was evaluated on the test dataset. The overall accuracy was computed, and the loss was analyzed to assess generalization.

Visualization of Predictions

To qualitatively evaluate both of the models, predictions were visualized as follows:

For the SVM model, a subset of test images was displayed with the corresponding true labels and predicted labels.

For the CNN model, the softmax outputs were used to determine which class each test image is most likely to be and visualized similar to the previous step.

This visualization allowed for a better identification of challenging samples and insights into how the models behaved.

RESULTS

The results for the SVM and CNN models show significant differences in performance for the image classification tasks. The SVM model, using the RBF kernel, reached a test set accuracy of 85.26% and reached a training set accuracy of 91.73%. Though its training accuracy is pretty high, the test set accuracy

shows a performance drop. It means that although the model is strong for linear classification, it struggles under the complexity of an image. SVMs are not designed to capture the intricate spatial relationships in images; hence they cannot learn complex patterns or features well, and, as a result, yield lower test-set accuracy than those that could specialize on their task.

In contrast, the CNN model showed a tremendous comparative performance by having an accuracy of 91.45% on the test set and of 97.70% on the training set. The trained CNN model over 30 epochs was in a position to take advantage of its convolutional layers for learning spatial hierarchies of features and, therefore, in effect, it enhanced the processing of image data. CNNs happen to effectively automatically detect textures, edges, and the complex structures contained in an image that surpass the performance of SVM classifiers in classification tasks for images. High training accuracy, paired with sound test set performance, indicates how well the CNN generalizes to unseen data and, therefore, makes it a better model for the problem.

Overall, both models performed very well, but the CNN handled image data and spatial complexity differently as such its performance for both training and testing improved significantly, making it the favorite model for image classification in this research.

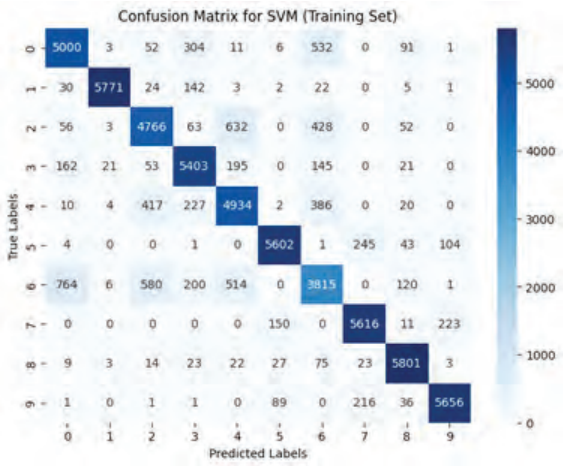

Fig. 4: Confusion Matrix for SVM (Training Set)

The performance of the SVM model on the training set, as depicted by the confusion matrix, was indeed quite impressive with most predictions made being correct. There were, however, certain classes that did not perform as well in terms of misclassification. The confusion matrix indicates that class 0, class 1, class 7 and class 9 fair very well in terms of accuracy as the number of misclassifications on them is relatively low. At the same time, however, there are other classes that do exhibit noticeable tendencies for misclassification. For instance, class 0 has a considerable number of samples, 532 to be precise, which were predicted to belong to class 5, while class 6 predicted 580 samples to belong to class 1 that were actually a part of it. This clearly indicates that there is some similarity between these classes that makes it difficult to differentiate between them for the classifier. On the other hand, the fact that there is some overlap between classes 3 and 5 is also a possibility given that they exhibit similar characteristics. All of these discrepancies clearly delineate the fundamentals of the SVM structure and show where it fulfills its purpose and where it does not, and the same holds true for the subcomponents of the model.

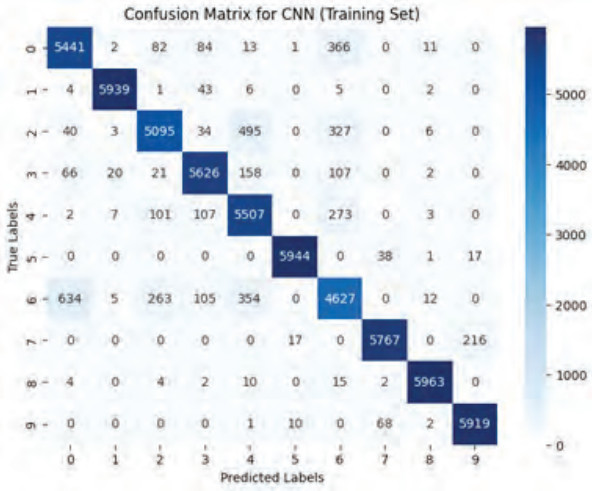

Fig. 5 : Confusion Matrix for CNN(Training Set)

The confusion matrix for the CNN model applied to the training set shows good classification performance with most values clustered on the diagonal. This seems to suggest that the majority of classes are predicted correctly. We see that class 0, class 1 and class 9 are quite accurate with barely any cases of confusion. We take note of some class confusion details such as 366 instances from class 0 being classified as class 5 and 263 instances of class 6 being recruited as class 3. Class 6 appears to be more widely confused than the others,

being misclassified into classes 3, 4 and 8 more often than into class 7. Regardless of a few mistakes, the CNN achieves comparatively high accuracy by being able to learn the spatial hierarchy of features. These results suggest that the model is able to successfully distinguish most features from other classes of the dataset, while also generalizing well on the dataset.

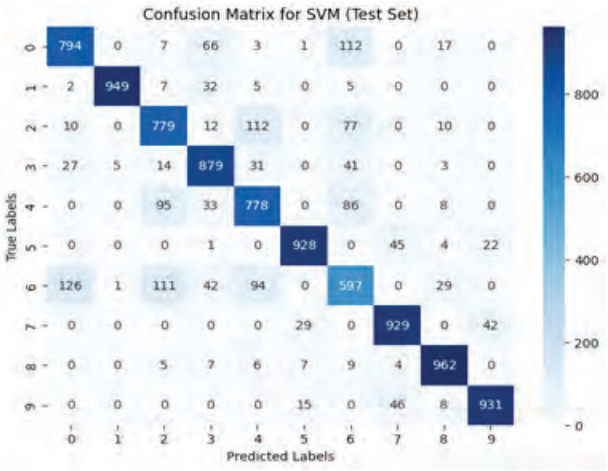

Fig. 6: Confusion Matrix for SVM (Test Set)

In terms of performance of the SVM model on the test set, most of the classes were able to achieve strong classification accuracy, whereby the diagonal values corresponded to the correct predictions made. For Class 0, a total of 794 correct classifications were made, though adequate classificiation into Class 6 was made of 112 instances. On the other hand, Class 1 performed outstandingly well and was able to make 949 correct predictions with little errors. Similarly for Class 2, a satisfactory level of 779 correct predictions were made with 4(112 instances) causing havoc with each other. Classes Three and Four had around 879 and 778 correct classifications, but a few instances were misclassified owing to mix-ups with nearby classes. Minimally flawed Class Five was able to reach 928 correct predictions. Class 6 suffered a setback with only 597 accurate classifications achieved with major instances of classifying as wrong Class 0 and 1 to 126 and 111 instances respectively. Judging by the performance of Class 7 and Class 8, doing well would seem to be predicting 9 and 962 correct predictions respectively. Showing 931 correct classification with some errors in classifying as Classes 5 and 8 was confident Class 9. The accuracy of the model in this case is up to the mark, however a few category were a bit troubling with example Class 6 difficulty being one that popped up frequently.

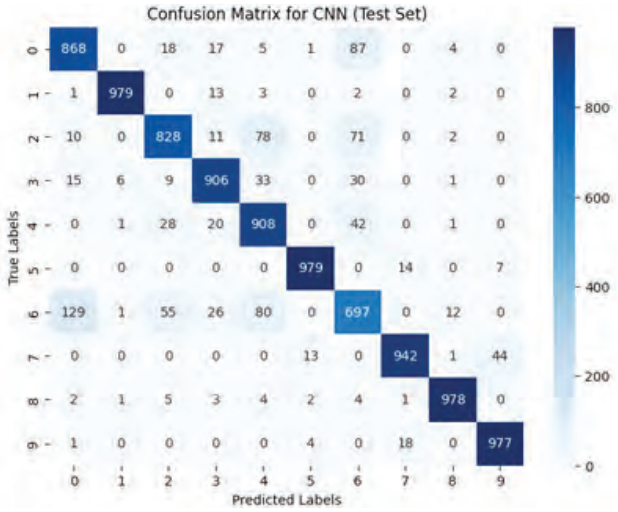

Fig. 7: Confusion Matrix for CNN(Test Set)

The matrix depicts how well the model was able to predict each class. The Y axis shows the actual labels while the X axis illustrates the predicted ones. The diagonal the diagonal elements depict instances of different classes which were correctly predicted and its value determines how well such an instance was classified. For instance, of the 868 samples of class 0, 0 was perfectly predicted, and of the 979 samples of class 1, 1 was perfectly predicted. Also contrarily to the O indicated elements, its counterpart does in fact have instances which were wrongly predicted, and they include 129 instances of class 6 which were predicted to be class 0. Prediction frequency is represented by the darkness of the blue color, the deeper the blue the larger the value of the prediction. A ruling can be made, that the greater number of predictions incorrectly predicted, the lesser the class performed or the inversion Class 6 had more errors than the others.

DISCUSSION

The results show that SVM and CNN do indeed excellently within different fronts of the image classification task but have various performances. The achieved relatively good training accuracy by the SVM model with an RBF kernel was at a considerable expense in test set accuracy, which has indicated that the task of capturing spatial relations within images

is quite challenging for SVM. Although SVMs are capable classifiers for linearly separable data, they fail to generalize well on the complex high-dimensional features present in image data. Also, the SVM's dependency on feature extraction and linear boundaries could impose a restricting interpretation when dealing with intricate patterns typical of image data.

The CNN performed better than the SVM both in training and on the testing sets. This proved deep learning importance in image classification because it enabled an automatic detection of a wide range of features, from edges up to complex structures, that helped CNNs effectively execute image data processing. During the training that was conducted for 30 epochs, it enabled the CNN to optimize its filters by the convolutional layers, thus contributing much to the very high accuracy in the test. Larger image data tasks with spatial dependencies, CNN outperforms because they are designed for hierarchical features learning; therefore, they are perfect for this image classification problem. That is to say, the higher test accuracy indicates that the CNN model becomes more robust and more robust to the unforeseen data while comparing to the SVM model.

More about benefits of CNNs in image classification than SVMs are presented, because they can learn to categorize spatial features and subtle patterns. Though SVM is a strong model that proves handy in usual classification problems, CNN can very well surpass it when handling the complexity of images and thus making CNN to be their related model.

CONCLUSION

The efficiency of a Support Vector Machine (SVM) and Convolutional Neural Network (CNN) models for image recognition in Fashion Mnist dataset was evaluated. The results showed that both models yielded positive results, with CNN performing better than the rest. The SVM model achieved high training accuracy but was unable to generalize well, which was reflected in its comparatively lower test accuracy. On the other hand, SVM outperformed with much higher test set accuracy and a better generalization of previously unseen data due to its built-in feature of hierarchical spatial learning using convolutional layers. The efficacy of the CNN in this task confirms its application to complex image classification problems where spatial information and intricacies are present.

Model	Training set Accuracy (%)	Test Set Accuracy (%)
SVM (RBF)	91.73	85.26
CNN	97.70	91.45

In conclusion, CNNs always outperform other models in regards image dataset tasks because they can effectively learn patterns. On the other hand, CNNs are the more preferred method in regards to image classification applications like waste classification as they do a poor job of addressing the issues presented with image datasets while SVMs do have some benefits when it comes to linear classification.

FUTURE SCOPE

In future research, exploring hybrid models that combine Convolutional Neural Networks (CNNs) with Support Vector Machines (SVMs) could enhance image recognition accuracy. Additionally, investigating advanced CNN architectures and Vision Transformers (ViTs) may further improve performance. Implementing data augmentation techniques and ensemble methods can also contribute to more robust models. Furthermore, applying transfer learning and attention mechanisms may lead to better generalization and focus on critical image features. Expanding research to include diverse and complex datasets will help assess the generalization capabilities of these models.

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A Data Mining Approach towards Automated Liver Disease Prediction with the Nested Dilated Cascaded LSTM Network

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ABSTRACT

Deep Learning (DL) approaches have recently emerged as a transformative force in machine learning, artificial intelligence and computer vision among other fields. As a result, researchers and enterprises remained substantially supported in the medical field, anticipating and regulating various ailments at particular time. Liver disease prediction is a critical step in analyzing and treating liver illnesses. The term "liver disease" indicates a wide range of illnesses that affect the liver. Common liver disorders include hepatitis, cirrhosis and liver cancer. Exact and early diagnosis is a pressing need in the prediction and diagnosis of liver disease. In this paper, implement a liver disease prediction network using a DL model and data mining methodologies. Initially, health data records from various liver patients can be acquired from standard resources and analyzed by utilizing the T-distributed Stochastic Neighbour Embedding (T-SNE) module. This can improve the visualization and exploration of high-dimensional data. These data can be transferred to the constructed Nested Dilated Cascaded LSTM (ND-CasLSTM) network, which is used to forecast various types of liver disease. Various experiments are conducted to demonstrate its usefulness and the result is validated against current deep learning approaches.

***KEYWORDS** : Data mining, Liver disease prediction, Long short-term memory, T-distributed stochastic neighbour embedding, Nested dilated cascaded LSTM.*

INTRODUCTION

In improper liver function (also known as liver disease), the liver's efficacy is significantly reduced if only 25% of it is still functioning while the remaining 75% is damaged [6]. Predicting liver illness at an early stage allows for earlier management, potentially preventing the disease from developing into more serious stages. Early treatment can stop or delay the progression of the disease, thereby improving patient outcomes. To that end, artificial intelligence technologies particularly machine learning models show a viable approach to solving a variety of classification and prediction challenges including liver disease [7]. Several algorithms have been proposed to predict and categorize liver disorders using machine learning [8]. ML approaches significantly hasten decision-making, reduce human error and implement the extraction of complicated patterns from data. However, developing an accurate machine-learning model can be difficult from many perspectives. The class disparity can occur when one diagnosis class has a significantly higher number of patients than the others. This discrepancy

can cause a bias in the model by lowering its prediction accuracy [9]. This bias often favours the majority class by increasing the minority class misclassification rate. Another cause for concern is the occurrence of missing values [10] in the clinical data due to time restrictions. For illustration, lost values are unavoidable for people who complete the questionnaire in the hospital.

However, liver illness can be diagnosed by medical imaging such as CT scans, MRI, sonography and ultrasound. The Liver Function Test (LFT) contains total bilirubin, direct bilirubin and a variety of other measures. These methods of diagnostics are expensive and time-consuming. As a result, applying intelligent methodologies is required to develop an accurate liver disease diagnosis system that is both cost and time-efficient. The intricacy and rarity of certain diseases in the absence of restricted symptoms in some diseases can provide significant hurdles to early detection and efficient treatment [11]. Another problem is that traditional diagnosis necessitates medical tests and human intervention. As a result, it is expensive and time consuming. Machine learning approaches can help to tackle some of these problems by lowering the cost and time necessary for medical examinations. Machine learning algorithms retrieve, analyze and predict vast amounts of medical and imaging data by allowing clinicians to make more accurate and efficient medical judgments. Predicting liver illness from a vast amount of medical data is a difficult task, but it has already been accomplished using machine learning techniques [12].

Doctors on the other hand can acquire information from each patient such as medical history, medical instruction, medical test results, X-rays, diagnosis, Magnetic Resonance Imaging, CT scan and so on. Further, this data can be transformed into a large amount of stored information and a vast storehouse of knowledge. On the contrary, if data is submerged it eventually provides a better vision of treatment and practical suggestions during diagnosis that enhance permissive improvement in the common syndrome which is applied to another defect resulting in the expansion of alternate procedures for treating specific diseases and so on [13]. Despite recent advances in machine learning, its trustworthiness can still be an issue, as the aforementioned data complexity can impair model reliability [14]. As a result, deep learning simulation aids medical personnel in passing over symptoms that have not previously been confirmed and can cause life-threatening consequences. Furthermore, methods such as deep learning ensure more efficient healthcare resources [15]. This study tries to provide this issue by removing deleted sequences and class imbalances from the data that allow the patient's endurance probabilities to be securely assessed. Despite all of these efforts to classify liver illness, there is no known approach/ method that yields a better prediction. Furthermore, the majority of previous research has used a tiny data set for model training and testing which has an impact on overall model prediction accuracy.

The contribution to the liver disease prediction network is described here.

- To design an efficient liver disease prediction using a data mining approach. This classification can achieve high accuracy in analyzing liver disease reduce the concern of misdiagnosis and enhance patient outcomes. Moreover, it can analyze the severity of the disease and helps to reduce the time needed for manual evaluation by clinicians.
- To utilize the t-SNE technique that helps to analyze the cluster or patterns and reduce high-dimensional data. Further, it can reduce the data for further analysis by decreasing the number of dimensions. It can improve the accuracy of predicting liver disease with the help of deep learning for effective prediction and diagnosis.
- To develop ND-CasLSTM for classifying liver disease and improve the feature extraction. The LSTM helps to capture long-term data within the clinical report. The nested dilated convolution enhances multi-scale patterns without losing the data and detects both local and global features efficiently. Additionally, this network implements the accurate classification module to analyze the disease stage and optimize the values in the network which helps the data to attain the exact diagnosed result.

The Introduction part of the paper is followed by different stages. Stage II indicates the literature review associated to liver disease. Further, the recommended model portrayal using deep learning approaches and the dataset details are provided in stage III. The feature

extraction mechanism is described in stage IV. The experimental result for the implemented liver disease is described in stage V. The conclusion for liver disease detection is provided in stage VI.

EXISTING WORKS

Related Works

In 2021, Hallaji et al. [1] have aimed to eliminate the respective obstacles in prediction to ensure the trustworthiness of the decision-making process. To achieve this goal, the researchers suggest a revolutionary deep learning strategy that could overcome these problems while also predicting the patient's chances of survival. Second, a hybrid framework was developed that consists of three primary modules for deleted data accusation, class disparity learning and organization in which each employs numerous advanced techniques for the particular task. Moreover, these two methodologies were contrasted and implemented by utilizing a real-world clinical case study. The investigational findings showed that the suggested DL method performed well in terms of the F-measure and the Area Under the Curve (AUC).

In 2019 An et al. [2] have proposed DeepRisk which was an entirely end-to-end model based on attention mechanisms and deep neural networks that can't learn high-quality features automatically from EHRs but also efficiently integrate heterogeneous and time-ordered medical data and predict patient's risk of cardiovascular disease. Evaluations were conducted on a real medical dataset and the result demonstrated that DeepRisk dramatically increased maximum-risk forecast accuracy for cardiovascular illness when compared to state-of-art methods.

In 2024, Al Ahad et al. [3] have introduced an adaptive data preprocessing strategy that aims to improve the efficacy of our fundamental machine learning models. The anticipated preprocessing mechanism received thorough testing. In addition, a set of ensemble models was suggested that combine basic ML classifiers to increase the accuracy of liver illness analysis. The exact mechanisms undergo intensive parameter optimization and demonstrated exceptional guidance and implementation accuracy. A user-friendly boundary was created to improve user engagement and practicality, allowing medical practitioners to easily enter patient sequence and quickly access assessments of the risk factors linked with liver illnesses.

In 2024, Drozdov et al. [4] have aimed to examine longitudinal electronic health record-based outcome prediction in MASLD using a cutting-edge machine learning algorithm. A deep-learning model for predicting all-cause death was developed using data from 940 individuals with histologically identified MASLD. Patient spanning 12 years were thoroughly accommodated, including clinical characteristics. A TNN functional to consistently obtained longitudinal electronic health information, performed well in predicting 12-, 24-, and 36-month all-cause death in MASLD patients. Our technique, when applied to population-level data, could allow for scalable and accurate risk classification to identify people who benefit most from anticipatory health care and personalized mechanism.

In 2024, Hendi et al. [5] have presented the effectiveness of multiple deep learning models in estimating and subtyping liver disease and prognosis. This manuscript proposes a novel approach called CNN+LSTM, which combines CNN with LSTM networks. The study's findings demonstrated that machine and deep learning could help in the diagnosis and prognosis of liver illness.

Research Gaps and Challenges

Liver Disease prediction through data mining helps in analyzing large health records and speeds the prediction of different disease types. Even though a lot of deep learning-based strategies are employed in this research as listed in Table 1, a few research challenges are still unaddressed.'

- Dimensionality has been a great concern in processing large health records. It is necessary to consider suitable data mining strategies to get access to high level features and improve the training speed of the prediction module. This can have a positive impact on processing large data records, and getting a timely diagnosis.
- Deep learning mechanisms are well capable of handling large data records, as they can be trained through a large set of layers. Still, concerns like computational complexity; and training speed are

not achieved up to mark. Developing LSTM-based deep learning modules helps in finding different and time-related features from the health record, and increases the scalability of the prediction network.

Table 1: Features and Challenges of Existing Data Liver Disease Prediction Model Inspired by Deep Learning Mechanisms

Author [citation]	Methodology	Features	Challenges
Hallaji, et al. [1]	Adversarial Imputation-Classification Network (AICN)	Addresses the data imbalance and predicts different types of liver diseases. Data imputation better analyses the health records and increases the prediction accuracy.	Predicts the survival rate in a limited set of data. Training complexity is not overcome.
An et al. [2]	AM with Deep learning	Has the ability to learn highly effective features. Effectively analyses the time-ordered data.	Even though has a high prediction rate for finding the high-risk cases, it is limited to small liver disease prediction.
Ahad et al. [3]	Ensemble model	Incorporates different data mining techniques to improve the prediction quality. Find the high-risk factors with high prediction rates.	Requires finetuning, and pre-processing to assess the missed data labels.
Drozdov et al. [4]	TNN	Better performance on the longitudinal EHR. Achieves high scalability as it trains high-risk levels in liver diseases.	Class distribution issues were not resolved. Less effective in large dimensional data.
Hendi et al. [5]	CNN-LSTM	Achieves diversity in large datasets. Suitable in processing multi-modal data.	Computational complexity in data training can reduce the effectiveness of the network.

NOVEL APPROACH OF LIVER DISEASE PREDICTION USING DATA MINING CONCEPT AND ITS DETAILS

Structural Representation of Proposed Liver Disease Prediction

Predicting liver disease at the early stage is difficult because of the subtle nature of initial symptoms. The liver disease can be analyzed by clinical examination to detect abnormal levels of liver enzymes. Moreover, deep learning can predict liver disease by analyzing the complex patterns in the medical images and enhancing diagnosis, staging and treatment monitoring for each patient. However, various techniques have been enhanced, but they face problems like be deficient in proper analysis of the recommended and conventional strategy. Furthermore, the existing model endeavours with some other issues like low-quality images, overlapping symptoms, inadequate use of liver biopsy and so on. Due to such eradicate processes; the existing model is not capable of implementing the better outcome. Hence, a novel detection model for liver analysis is enhanced to predict the exact outcome. Therefore, the architectural representation of liver disease is shown in Fig. 1.

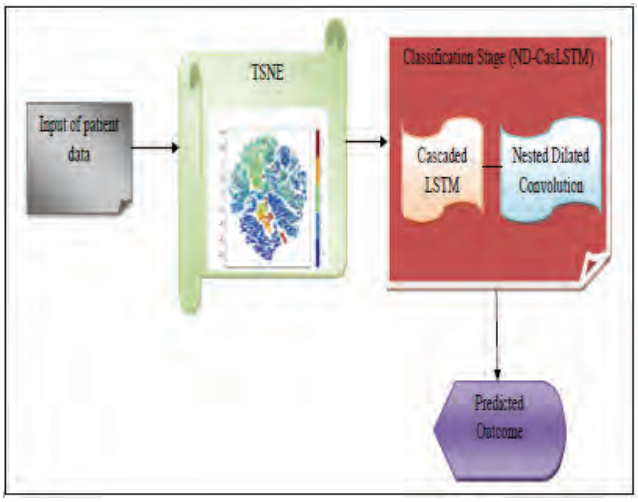

Fig. 1. Diagrammatic view of novel approach of liver disease prediction using nested deep learning network.

The liver classification model is introduced in this work for enhancing early treatment plans and diagnosis. First, the liver predictions are analyzed from the medical image to detect the stage and for further classification.

In liver disease prediction, t-SNE is largely utilized for feature extraction mechanisms. It aids researchers in comprehending intricate linkages found in high-dimensional liver disease data. By implementing the data into a reduced-dimensional space, t-SNE makes it easier to find clusters or patterns that can signal distinct liver disease conditions or stages. Moreover, it cannot be directly used to predict liver disease and can mislead interpretation when analyzing the overall disease. Hence, the new model ND-CasLSTM is introduced with the cascaded concept. This network is developed by the amalgamation of the LSTM network with the added sequence of nested dilated convolution. Once the input is fed into the LSTM it can handle the time-series and sequential medical data to predict the liver disease. It helps to predict the irregular data and analyse the fatty liver in the early stages. Though this network can predict liver disease it estimates less accuracy and lacks in handling the long sequential data. The nested dilated convolution is the added network that enhances feature extraction from complex medical data in handling temporal and spatial patterns. It can extract the features even from the noisy data to improve the prediction reliability. Hence, the overall network ND-CasLSTM is implemented with effective features to provide classified outcomes. This network is a combination of convolutional and recurrent networks that can effectively handle temporal data. It can strengthen the convolutional network and implement robust and accurate systems in liver disease. Finally, the suggested model is implemented with an effective result and outperforms the detection processes rather than the conventional approaches.

Acquisition of Data Details

The data collected from the patients diagnosed with different liver conditions consists of both healthy and affected liver records. The data sources are explained below:

Dataset ("Liver Patient Records"): This feature is accessed by "https://www.kaggle.com/datasets/uciml/indian-liver-patient-records" access date: 05-05-2025. Patients with liver disease have been gradually growing as a result of unnecessary alcohol utilization, breathing of toxic gas and intake of infected food and medications. This dataset helps to predict liver disease and reduces the burden for physicians.

From the above-mentioned dataset, the gathered data is signified as , here and the overall data count is obtained from these resources and specified as .

FEATURE EXTRACTION MECHANISM AND EFFECTIVE DEEP LEARNING MODEL FOR LIVER DISORDER

T-SNE for Feature Extraction

The t-SNE [20] is an iterative approach for visualizing high-dimensional data that maps data points to a two- or finite-dimensional space. The gathered image is given as the input. This method uses a nonlinear dimension reduction methodology to generate a single map that displays the fundamental features of a high-dimensional dataset including trends, patterns, and outliers. To alleviate the crowding issue and make SNE more resilient to outliers, t-SNE was introduced with a symmetrized version of the SNE cost function with simpler gradients. The Eq. (1) represents the feature of SNE.

$$S_{b|a} = \frac{\exp\left(-\left\|k_a - k_b\right\|^2 / 2\tau_a^2\right)}{\sum_{n \neq a} \exp\left(-\left\|k_a - k_n\right\|^2 / 2\tau_a^2\right)} \quad (1)$$

Here, $S_{b|a}$ indicates the probability distribution, k_n is the effective number of local neighbours and 2τ indicates the binary function of the Gaussian distribution function.

Moreover, the t-SNE with the Gaussian function is described in Eq. (2).

$$m_{a,b} = \frac{\left(1 + \left\|c_a - c_b\right\|^2\right)^{-1}}{\sum_{s \neq l}\left(1 + \left\|c_x - c_l\right\|^2\right)^{-1}} \quad (2)$$

Here, $m_{a,b}$ representing the t-SNE with a distributed function, C_a, C_b indicates the cost function, $\sum_{s \neq l}$ indicates the Gaussian function m. As a result, a feature M_s is extracted to predict the liver disease.

Developed ND-CasLSTM for Prediction

To predict liver disease, the extracted features are given as the input. From, this input the LSTM networks can detect dependency across time in serial data and overcome vanishing gradients. LSTM networks include memory cells and many gating techniques

to control data transfer over the network, which is a form of recurrent neural network. The model for each recurrent node is a conventional LSTM structure, with gates controlling memory cell states. They manage information flow by updating or discarding statistics from memory cells based on recent and past input. This allows LSTMs to develop long-term dependence by remembering relevant information over multiple time steps. This model implements both spatial and temporal features to enhance the accurate diagnosis. The LSTM is described in Eq. (3)

$$
\begin{aligned}
s_h &= \sigma\left(D_s \cdot \left[j_{p-1}, M_s\right] + k_s\right) \\
m_h &= \sigma\left(D_m \cdot \left[j_{p-1}, M_s\right] + k_m\right) \\
r_h &= \tanh\left(D_r \cdot \left[j_{p-1}, M_s\right] + k_r\right) \\
c_h &= \sigma\left(D_c \cdot \left[j_{p-1}, M_s\right] + k_c\right) \\
l_h &= m_h \Theta l_{h-1} + s_h \Theta r_h \\
o_h &= c_h \Theta \tanh\left(l_h\right)
\end{aligned}
\qquad (3)\sigma\sigma
$$

Here, σ represents the sigmoid function with the output range of [0,1], represents the hyperbolic tangent function with the output range of [-,1], Θ indicates the elementwise multiplication, m_h indicates the extent function of the old memory cell, S_h indicates the recent data stored in the recent cell, C_h represents the output based on the memory cell, l_h represents the feature map position, j_{p-1} represents the hidden state of the function h_p represents the current time of the memory. In nested convolution, a multi-level convolutional approach is applied in a structured, layered manner within a single network module. Nested convolutions [21] involve embedding convolutional layers within the blocks that capture both fine and coarse features simultaneously. It can capture intricate tissue structures and variations at multiple scales. This leads to more accurate classification of liver lesions, fibrosis stages, or tumour boundaries and helps improve the robustness and precision of liver disease detection systems.

The cascaded technique is combined with the LSTM model which involves stacking multiple LSTM layers, where the output of one layer becomes the input for the next. This structure enables the model to learn hierarchical patterns in sequential data such as patient records, liver function test results, or imaging time series. This architecture helps to extract more abstract and informative features by improving the detection, classification, and prognosis of liver diseases. Moreover, cascaded LSTM implements more accurate and early diagnosis of liver-related conditions. Further, the nested dilation convolution is added to predict liver disease. Dilated convolution is also termed as convolution with a dilated filter which resolves the problem by expanding the kernel size without increasing the calculation. In dilated convolution, holes are inserted between the filter elements, allowing the network to capture broader contextual information while preserving resolution.

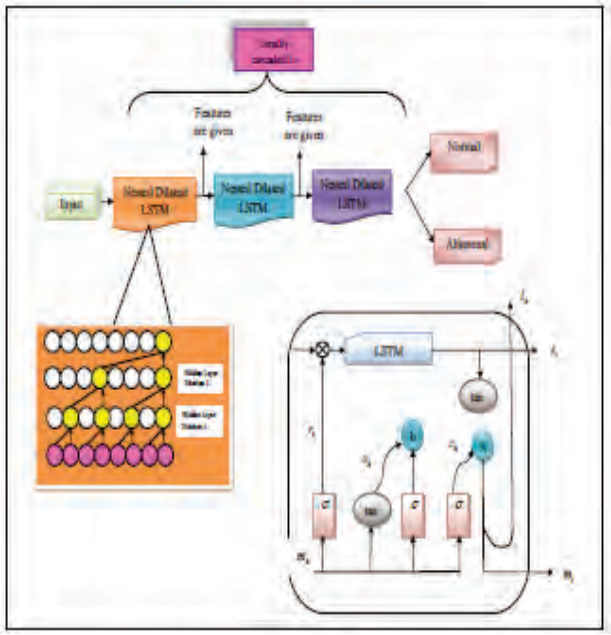

Fig. 2. A structured view of designed ND-CasLSTM for liver prediction

RESULT AND DISCUSSION

Experimental setup

The recommended liver disease identification framework was executed by Python. Further, by employing models such as Artificial Intelligence and Capsule Networks (AICN) [16], Long Short-Term Memory (LSTM) [17], Thresholding Neural Networks (TNN) [18] and Artificial Neural Networks (ANN) [19] were taken for analyzing the model's performance with various measures.

Performance Analysis

The designed ND-CasLSTM performance validation for liver disease is showcased in Fig.3. This investigation considers significant measures to determine the efficacy of the model. The accuracy of ND-CasLSTM is 95.8%, 87.25 of AICNN, 90.7% of LSTM and 91% of ANN with the first dataset respectively. Thus, these investigations guaranteed that the designed ND-CasLSTM can allow secure and reliable healthcare solutions.

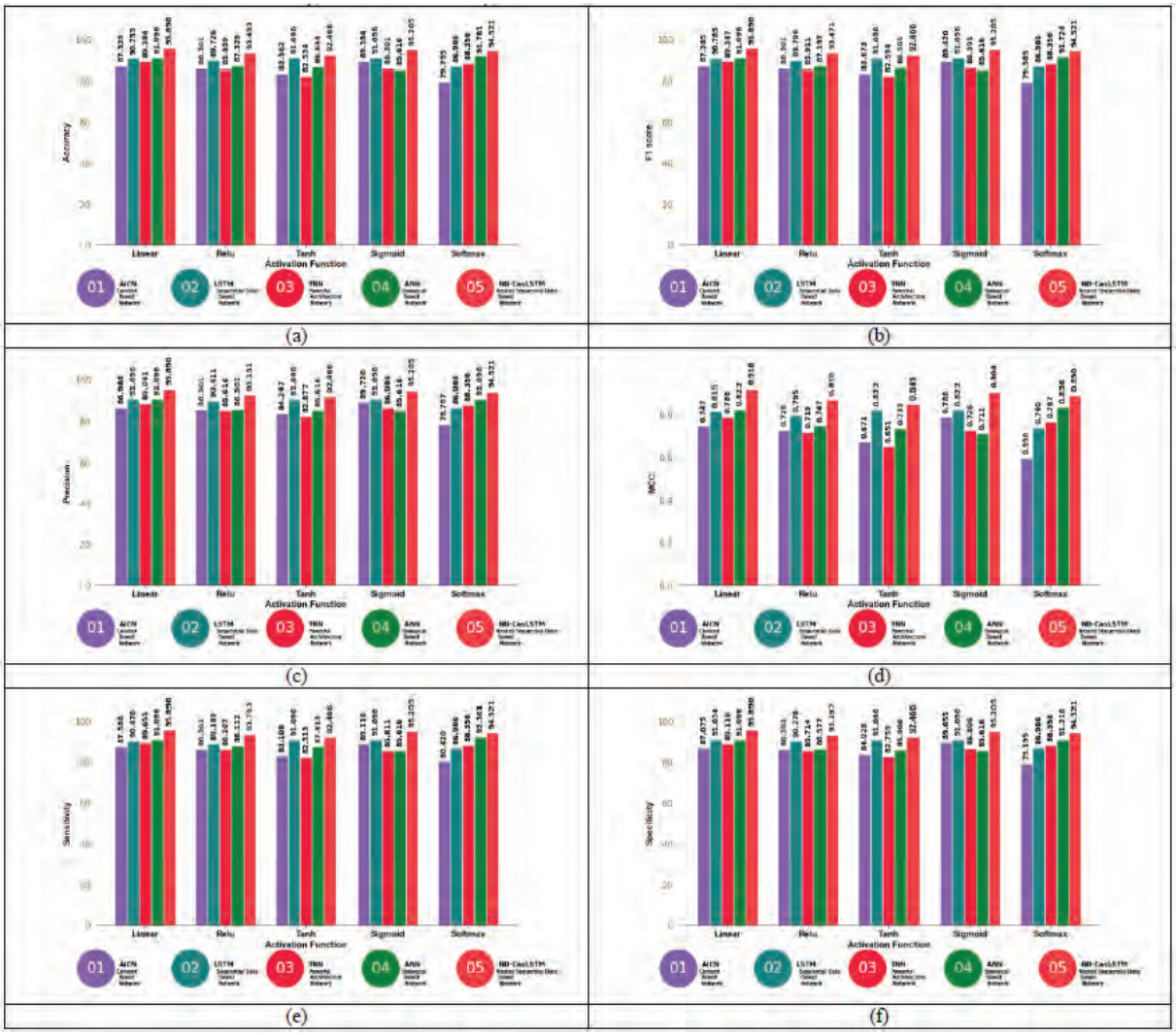

Fig. 3. Performance analysis of the designed ND-CasLSTM for liver detection system over existing system in terms of (a) Accuracy (b) F1 score (c) Precision (d) MCC (e) Sensitivity and (f) Specificity

Accuracy evaluation

The accuracy for the developed ND-CasLSTM is optimized with Table II. The standard deviation is exploited for analyzing the functionality of the ND-CasLSTM. The accuracy for ND-CasLSTM is 90% higher than AICN, 80% more than LSTM, 84% advanced than TNN and 86% higher than ANN, respectively. The finding enhances that ND-CasLSTM is increased and it reduced the complexity classification. Hence, the classification becomes effective when compared with previous approaches.

Table 2. Accuracy Evaluation of and-Caslstm Analysis Compared with the Existing Approach

Epochs	AICN [16]	LSTM [17]	TNN [18]	ANN [19]	ND-CasLSTM
5	80.1369863	84.24657534	90.75342466	86.30136986	95.89041096
10	88.01369863	92.46575342	92.12328767	85.95890411	93.49315068
15	85.61643836	93.15068493	84.24657534	92.46575342	92.46575342
20	83.90410959	84.93150685	87.67123288	87.67123288	95.20547945
25	86.98630137	92.46575342	84.93150685	87.32876712	94.52054795

CONCLUSION

This article implemented a classification system for liver disease by analyzing different strategies. The health data record was initially gathered from the standard databases. Further, the t-SNE was utilized for extracting the relevant features from the input data. Finally, the resultant features were processed under the ND-CasLSTM for forecasting the liver disorder. Lastly, the proposed system has been examined with distinct measures to provide the outcome. The accuracy of ND-CasLSTM has achieved higher values than 95%, 90%, 89% and 87% for AICN, LSTM, TNN and ANN, respectively. From this analysis, it was portrayed that the recommended deep learning model in liver disease identification was more effective and accurate than the other previous models.

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Application of Artificial Intelligence in Strategic Restaurant Marketing

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ABSTRACT

Food industry is growing day by day. These days it is becoming an important part in a country's economy. Many new companies are establishing daily that are working in the food business which provides food at door steps. These platforms have not only made a revolutionary change in the food industry but it is also providing jobs to many people. Now Indian food sector particularly the online food supply chain is innovating daily. New challenges are coming and they are overcoming the new challenges with the help of Artificial intelligence also fulfilling the customer's demand without compromising the quality. They are providing these facilities at a reasonable price.

KEYWORDS *: Machine learning, Data sets, Algorithm.*

INTRODUCTION

Introduction to Food Business: The food industry in India has seen significant growth, playing a vital role in the country's economy and contributing substantially to employment and GDP [13]. The restaurant business, in particular, has expanded rapidly. These digital platforms not only offer convenience and transparency but also enable restaurants to reach a wider audience and increase their market penetration [30]. Thus, the Indian food industry, particularly the online restaurant sector, is poised for continued growth and innovation.

Food Outlet Customer Requirement

Food outlet service satisfaction is a critical component in the competitive landscape of the restaurant industry in many Asian countries, including Malaysia, where customer expectations are diverse and constantly evolving [35] [17]. Services cape, encompassing the physical environment and ambiance, significantly impacts customers' perceptions of service quality and their subsequent behaviours [2] [15].

Types of Restaurants

Food outlets can be broadly classified based on various factors such as service style, price levels, and menu offerings, reflecting both historical and contemporary trends in the restaurant industry. Historically, classifications such as grills, oyster bars, and coffee houses have evolved, giving rise to modern counterparts like pizzerias and steakhouses, which retain similar concepts and service styles [18] [36]. Additionally, the US Census Bureau and industry organizations like Hoovers categorize restaurants into subtypes such as full service, limited service, and specialty eateries, further refining the distinctions within the industry [10] [26]. This segmentation helps in understanding the diverse landscape of food outlets, providing a structured vocabulary for both industry participants and researchers to discuss and analyse restaurant operations effectively [23].

Introduction to Online Food Delivery: The rise of internet usage and ecommerce platforms has revolutionized

the food service industry, significantly altering how consumers engage with various types of food outlets. These online food delivery service platforms provide an incredible level of convenience, enabling customers to order food using their smartphones and have it delivered right to their doorsteps. This trend is largely influenced by the fast-paced lives and busy schedules of urban dwellers. As a result, we are seeing a transformation in traditional food ordering methods, along with a new level of accessibility and ease that mirrors the evolving habits of consumers and advancements in technology.

LITERATURE REVIEW

Literature on Restaurants & OFD Apps

Reference No	Objective	Source	Technique/Method	Results
[22]	To analyse the relationship between sustainability practices and the degree of innovation in restaurant services and to identify relevant restaurant segments for developing effective awareness and training actions.	300 valid questionnaire s completed by restaurant owners or managers from coastal Ecuador.	Segmentation analysis using the CHAID algorithm.	Three restaurant segments were identified: The value of chain is focused by sustainable innovators, saving resources is focused by moderate innovators, and low innovative profile restaurants.
[8]	To investigate the factors impacting customer satisfaction in the restaurant industry in Kabul, Afghanistan	Customer satisfaction surveys from restaurants in Kabul.	Linear regression analysis.	Customers prioritize cultural issues such as respect for family privacy over service quality factors like food quality, employee behaviour, and restaurant atmosphere
[25]	To analyse the demographic profile of respondents and their positive attitude towards online food delivery (OFD) apps.	Primary data gathered via a questionnaire. Secondary data from academic research findings, journal publications, newspapers, and magazines.	Descriptive research design with simple random sampling of 50 respondents, using Frequency Distribution, Descriptive Statistics, Chi-square Analysis, and Garrett Ranking.	The majority of respondent s are young, unmarried males who are attracted to OFD apps primarily due to visual appeal and price comparison features.

Literatures on Segregation Prediction Modelling

Reference No.	Objective	Source	Technique/Method	Results
[33]	Enhance e shopping quality by adding a regional factor to product recommendations, addressing the over similarity problem in traditional prediction methods.	Area wise data, specifically country-based segregation focusing on India, including its culture, handicrafts, and citizens. Existing customer demographic details are also considered.	The proposed predictive system uses a framework that inputs datasets based on multiple attributes, combining database and user query inputs to generate suggestions.	A framework is proposed to improve e shopping recommendations by incorporating regional data to provide novel product suggestions.

[22]	To analyse the relationship between sustainability practices and the degree of innovation in restaurant services and to identify relevant restaurant segments for developing effective awareness and training actions.	300 valid questionnaires completed by restaurant owners or managers from coastal Ecuador.	Segmentation analysis using the CHAID algorithm.	Three restaurant segments were identified: The value of chain is focused by sustainable innovators, saving resources is focused by moderate innovators, and low innovative profile restaurants

Literatures on Other Predictive Modelling

Reference No	Objective	Source	Technique/Method	Results
[37]	To determine the ability of machine learning regression models to assess the variability in total fat content concerning SFA, MUFA, and PUFA in US consumed snacks between 2017 and 2018	The National Health and Nutrition Survey (NHANES)	Machine learning regression models including ANNs, DTs, KNNs, SVMs, linear regression, XGR, Light GBM, and RF using NHANES 24hour recall data.	KNNs and DTs predicted fatty acids with specific MSE values, SVMs failed, ANNs performed satisfactorily, and ensemble methods.

CONCLUSION

This research tackles significant deficiencies in the amalgamation of segmentation and predictive modelling to optimize marketing strategies for eateries. Although studies by [33] and [29] demonstrate the effectiveness of predictive models in various scenarios, they fail to include segmentation, indicating a notable deficiency. Similarly, [22] and [25] concentrate on segmentation factors like sustainability and customer satisfaction without leveraging predictive analytics to improve marketing initiatives. Additionally [5] and [32] demonstrate the potential of predictive modelling and AI/ML techniques, but their work lacks the customization needed for restaurant segments. This study presents a comprehensive AI-driven framework that integrates segmentation by cuisine, location, and other parameters alongside sophisticated predictive models. By integrating these methodologies, the study seeks to offer a nuanced understanding of customer preferences and behaviours, enabling tailored and effective marketing strategies. The application of AI/ML techniques will further refine these strategies, particularly in predicting customer churn and optimizing engagement. Ultimately, this approach guarantees to enhance customer satisfaction and offer a notable competitive edge in the dynamic restaurant industry.

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Switching Median Filter for Removing Impulse Noise from Color Medical Images

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ABSTRACT

In this paper, a switching median filter is proposed to remove impulse noise from color medical images that are corrupted by salt and pepper noise. In the impulse noise detection step, we use the difference between the average of the first five ordered aggregated distances and the center pixel to identify whether the center pixel is likely corrupted. In the second stage, these likely corrupted pixels are judged by using the minimum difference between the center pixel and other pixels in the four edge directions in the window. The results of the experiment show that the proposed filter performs better in terms of PSNR and detail preservation.

KEYWORDS *: Impulse noise, Vector median filter, Switching filter, Color medical image, Salt and pepper noise.*

INTRODUCTION

Noise filtering is one of the most common image processing tasks. The presence of noise in an image degrades the image quality, causing difficulties in various image processing tasks. Color images are often corrupted by impulse noise due to the aging of the storage material or during transmission, due to the natural or man-made processes, malfunctioning sensors in the image formation process, etc [1]. Nowadays, color medical images are widely used by medical practitioners and researchers for the diagnosis and detection of diseases [2].

Removal of impulse noise from images is very important. Impulse noise and edge pixels are very similar, and edge detection operators are also sensitive to noise. So, before doing any processing, we need to remove noise from that image.

In a color image, there are three channels, Red, Green, and Blue, and there is a strong correlation between these channels. So, for the processing of color images, vector processing is preferred as it retains the correlation between the three channels, and no color artifacts are introduced. And nonlinear vector processing of the color image is the most effective way to filter out noise. The popular filters for removing impulse noise from color images are nonlinear filters based on the ordering of vectors in the filtering window. In these filters, the output is the lowest-ranked vectors ordered according to a specified ordering technique. Vector median filter (VMF)[3], basic vector directional filter (BVDF)[8], and directional distance filter(DDF)[9] are the classical nonlinear vector filters that are used for removing impulse noise from color images.

One of the disadvantages of these filters is that they perform filtering operations to all the pixels, which results in the blurring of edge and texture. An optimal filtering situation could be achieved if only the noise-affected pixels could be identified and restored. In order to achieve the optimal filtering situation, various

switching filters are proposed in the literature for removing impulse noise.

This paper proposes a switching nonlinear vector filter for removing impulse noise from color medical images. In the impulse noise identification step, we find out the average of the first five aggregated distances calculated for all vectors in the filtering window. Then the difference between the central vector and the average is calculated, and it is compared to a predefined threshold. If the difference is very large, then it may be an outlier or edge pixel. To confirm, we further check if this pixel is connected to any of the edge orientations. If it belongs to any edge orientation, then it is an edge pixel; else, it is an impulse. Only impulse pixels are substituted by the output of the vector median filter, while others are left unchanged.

PROPOSED METHOD

A 3 × 3 filter window, as shown in Fig. 1, is used for the filtering process.

v1	v2	v3
v4	v5	v6
v7	v8	v9

Fig. 1. A 3 × 3 filter window

The vector v5 is the central pixel that is to be processed. We used this sliding window to process all pixels in the image. First the sum of the aggregated distance of each vector to all other vectors in the filtering window, as was done in the VMF, is calculated using

$$D_i = \sum_{j=1}^{N} \|x_i - x_j\| \quad for\ i = 1, 2, \ldots, N \tag{1}$$

$$\|v_i - v_j\| = \left(\sum_{k=1}^{m} |v_{ik} - v_{jk}|^{\gamma}\right)^{1/\gamma} \tag{2}$$

The average of the first five sorted aggregated distances is calculated. We find out the difference between the central pixel and the average of the first five sorted aggregated distances. If the difference is greater than a threshold, then it is considered probably noisy. Impulse noise has very similar characteristics to edge pixels. Both impulse noise-affected pixels and edge pixels have abrupt transitions. But if a pixel is a part of an edge, then there will be some other similar pixels in the filter window. So, in order to verify whether this pixel is an edge or impulse, we need to check the connectedness of the central pixel in the four edge directions of the filter window using the following equations.

$$E_1 = \frac{1}{2}\left(d(v_5, v_4) + (q_5, q_6)\right) \tag{3}$$

$$E_2 = \frac{1}{2}\left(d(v_5, v_3) + (v_5, v_7)\right) \tag{4}$$

$$E_3 = \frac{1}{2}\left(d(v_5, v_2) + (v_5, v_8)\right) \tag{5}$$

$$E_4 = \frac{1}{2}\left(d(v_5, v_1) + (v_5, v_9)\right) \tag{6}$$

This probably noisy pixel may be a noise or edge pixel. If it is an edge pixel, then it will be a part of the horizontal, vertical, or diagonal direction. Therefore, we calculated the pixel difference in the above four directions. The minimum of the four is compared to a threshold value. If the pixel is an edge pixel, then one of the results will be very low. If it is noisy, then it is replaced by the output of a vector median filter.

The proposed filter (PF) is represented as:

$$PF = \begin{cases} VMF, & if\ abs(avg\ of\ first\ five\ ordered\ distance - r_c) > Td\ and\ V_{min} > Tol \\ v_5, & unchanged \end{cases} \tag{7}$$

EXPERIMENTS

Noise model

The following impulse noise model[1] is used for our experiment:

$$\boldsymbol{n(x)} = \begin{cases} \boldsymbol{x} \text{ with probability } 1 - \varphi \\ (r1, x2, x3)^T \text{ with probability } \varphi 1.\varphi \\ (x1, r2, x3)^T \text{ with probability } \varphi 2.\varphi \\ (x1, x2, r3)^T \text{ with probability } \varphi 3.\varphi \\ (r1, r2, r3)^T \text{ with probability } \varphi.\varphi\Sigma \end{cases} \tag{8}$$

where n(x) is the noisy signal, x=(x1,x2,x3)^T represents the constant noise free vector pixel, r = (r1, r2, r3)T is a random vector that represents the impulse noise and takes values either 0 or 255. φ is the sample corruption

probability, φ1, φ2, φ3 are the corruption probabilities of the channel nad φΣ =1-φ1-φ2-φ3 represents the impulse noise value.

Evaluation metrics used for measuring the performance of the filter are PSNR (peak signal to noise ratio), normalized color distance (NCD), MAE(mean absolute error), True detection, and False detection. The formulas for PSNR, NCD, and MAE are given below. NCD measures the perceptual error in the CIELab color space, PSNR measures noise suppression capability, and detail preservation capability by MAE. An efficient filter should have a low MAE and NCD while having a high PSNR.

$$PSNR = 10\log 10\left(\frac{255^2}{\frac{1}{3MN}\sum_{m=1}^{M}\sum_{n=1}^{N}(d(q(m,n),f(m,n)))^2}\right) \quad (9)$$

$$NCD = \frac{\frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M}\sqrt{(L^o(i,j)-L^x(i,j))^2+(u^o(i,j)-u^x(i,j))^2+(v^o(i,j)-v^x(i,j))^2}}{\frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M}\sqrt{(L^o(i,j))^2+(u^o(i,j))^2+(v^o(i,j))^2}} \quad (10)$$

$$MAE = \frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M}\left|o_{i,j}-x_{i,j}\right| \quad (11)$$

Standard color images [4,5,6,7] are used for our experiment. Fig. 3 shows some of the standard color images of size 512 x 512. State-of-the-art filters meant for impulse noise removal are selected for evaluating the efficiency of the proposed method. VMF [3], AVMF [10], MSMF [11], RWASF [12], SFLCPG [13], and FASTAMF[14] are chosen. Experiments are performed using MATLAB version R2015a on a system with an i5 processor at 1.80 GHz. To maximize the efficacy of the proposed filter, we have to find the optimal value of Tol. It is found that the PF performs best at td=150, Tol=35. The parameters of the other filters used for comparison are shown in Table 1. The parameters are set according to the appropriate recommendation given in the references. Simulation results of the PF on Lena, duodenal_ulcer, and brain images compared with the selected filters VMF, AVMF, MSMF, RWASF, SFLCPG, and FASTAMF are shown in Table 2, Table 3, and Table 4, respectively.

Table 1. Parameters of the different filters

Filters	Parameters
AVMF [10]	Tol=35
MSMF [11]	Tol=30
RWASF [12]	Tol=65
SFLCPG [13]	LT=75

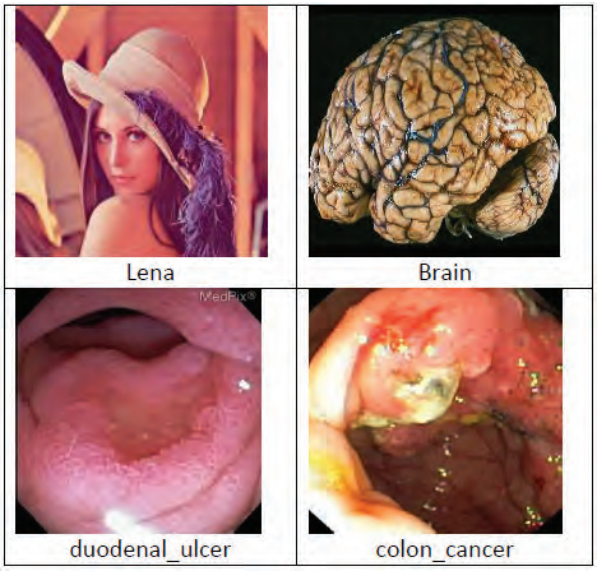

Fig. 1. Images used in this experiment

Table 2. Comparison of PF in Lena image

Noise	Parameter	VMF	AVMF	MSMF	RWASF	SFLCPG	FASTAMF	PF
10%	NCD	0.0213	0.0060	0.0065	0.0043	**0.0030**	0.0152	0.0034
	PSNR	31.76	34.5481	34.5459	38.6144	37.5982	35.9275	**38.7053**
	MAE	3.72	1.1225	1.1370	0.5137	0.6516	0.7238	0.5093
20%	NCD	0.0199	0.0071	0.0073	0.0156	0.0158	0.0165	**0.0058**
	PSNR	31.31	33.7415	33.5821	34.6803	34.1587	30.5016	**34.6847**
	MAE	3.9390	1.4881	1.5466	1.0246	1.1337	1.6138	**1.0162**
30%	NCD	0.0168	0.0076	0.0080	0.0166	0.0164	0.0183	**0.0066**
	PSNR	30.76	32.5868	32.7317	31.6931	32.9593	27.2451	**33.2979**
	MAE	4.1923	2.0187	1.9457	1.6025	1.6144	2.7240	**1.0581**

40%	NCD	0.0198	0.0100	**0.0088**	0.0181	0.0172	0.02 12	0.0172
	PSNR	30.14	31.4450	31.9360	28.5323	31.5278	24.4919	**32.0371**
	MAE	4.4895	2.5892	2.3394	2.4019	2.1622	4.2061	**2.0403**
50%	NCD	0.0220	0.0188	0.0130	0.0205	0.0183	0.0252	**0.0108**
	PSNR	29.34	30.2596	31.0874	25.9293	29.1122	22.3626	**31.5706**
	MAE	4.8354	3.2416	2.7553	3.4435	2.8268	5.9991	**2.4515**
60%	NCD	0.0212	0.0131	**0.0101**	0.0237	0.0198	0.0303	**0.0101**
	PSNR	28.34	29.0210	30.2444	23.7452	27.1659	20.5385	**30.9955**
	MAE	5.2953	3.9806	3.1704	4.7812	3.6436	8.1704	**2.9094**
70%	NCD	0.0225	0.0214	**0.0195**	0.0280	0.0246	0.0383	0.0197
	PSNR	27.11	27.6775	29.4524	21.3832	23.0957	18.7143	**29.5214**
	MAE	5.8971	4.8263	3.5758	6.4549	5.4581	11.5096	**3.4027**

Bold values indicate best results

Table 3. Comparison of PF in Duodenal Ulcer

Noise	Parameter	VMF	AVMF	MSMF	RWASF	SFLCPG	FASTAMF	PF
10%	NCD	0.0087	0.0015	0.0022	0.0014	0.0020	0.0020	**0.0014**
	PSNR	39.4251	40.3114	36.0748	40.5533	36.5626	35.2647	**40.7740**
	MAE	0.8368	0.2895	0.4264	0.2605	0.3694	0.1788	**0.1603**
20%	NCD	0.0091	0.0022	0.0026	0.0024	0.0028	0.0041	**0.0021**
	PSNR	38.6535	38.9878	35.7685	36.9986	34.3210	30.0448	**38.9887**
	MAE	0.9649	0.4429	0.5443	0.4829	0.5856	1.5749	**0.4373**
30%	NCD	0.0104	0.0028	0.0031	0.0036	0.0035	0.0069	**0.0026**
	PSNR	37.9931	38.0731	35.5174	33.5781	33.8553	26.8067	**38.1009**
	MAE	0.9649	0.6202	0.6652	0.8027	0.7510	2.6285	**0.5466**
40%	NCD	0.0104	0.0037	0.0032	0.0058	0.0042	0.0069	**0.0032**
	PSNR	36.7980	36.5620	35.1629	29.7962	33.0379	26.8067	**37.5525**
	MAE	1.3134	0.8415	0.8054	1.3712	0.9488	2.6285	**0.6942**
50%	NCD	0.0097	0.0047	0.0042	0.0088	0.0057	0.0161	**0.0038**
	PSNR	35.0863	35.0845	34.6638	26.9240	30.3827	22.0999	**35.9513**
	MAE	1.5758	1.1238	0.9602	2.1959	1.3690	5.7573	**0.8595**
60%	NCD	0.0070	0.0060	0.0048	0.0132	0.0076	0.0224	**0.0045**
	PSNR	33.6133	33.6841	33.9621	24.4725	28.0456	20.3632	**35.1239**
	MAE	1.9287	1.4740	1.1339	3.3915	1.8655	7.8232	**1.0258**
70%	NCD	0.0084	0.0077	0.0055	0.0186	0.0136	0.0301	0.0052
	PSNR	31.9561	31.7308	33.2150	22.4891	23.1483	18.3902	34.1933
	MAE	2.3578	1.9468	1.3164	4.9022	3.5360	10.2166	1.2095

Bold values indicate best results

From the experimental results shown in Table 2 of Lena image, it is found that the RWASF works well at low noise density (10% and 20%) than other filters, and the results are very close to SFLCPG and PF. The PF performs better than other filters at noise density ranging from 30% -70%. For the duodenal_ulcer image, the AVMF has the highest PSNR at 20% noise density, while the PF has the highest PSNR from 30% to 70%, and the lowest MAE and NCD for all noise density ranges, which shows that the proposed filter can remove noise and can retain image details better than other filters. For the brain image shown in Table

4, the RWASF works better than the other filter at low noise (10% and 20%) density, and our PF gives better results at other noise densities. It is also noticed from the experimental results that the performance of the PF is very near to RWASF at low noise density.

Fig. 5 shows the performance of the filters for colon_ cancer image. The proposed filter has highest PSNR value at low, medium, and high noise density. From the figure, it is seen that the proposed filter has the highest PSNR value than the other filters like VMF, AVMF, MSMF, RWASF, SFLCPG, and FASTAMF. Since the proposed filter used a detection technique that employs both the difference between the center pixel and average of the first five ordered pixels to identify whether that noisy candidate pixel is either an edge or thin lines make the proposed filter outperforms other filters. The performance comparison in terms of MAE for colon_ cancer is shown in Fig. 5, and in terms of NCD for the same images is shown in Fig. 6.

Table 4. Comparison of PF in brain image

Noise	Parameter	VMF	AVMF	MSMF	RWASF	SFLCPG	FASTAMF	PF
10%	NCD	0.0408	0.0225	0.0273	0.0087	0.0173	0.0098	0.0074
	PSNR	26.9538	27.8702	27.4906	30.3929	29.5016	29.1817	30.4376
	MAE	4.9976	2.9141	3.1813	1.2408	1.5520	1.7090	1.2023
20%	NCD	0.0396	0.0273	0.0277	0.0128	0.0134	0.0156	0.0127
	PSNR	26.5501	27.3712	27.0587	29.0861	28.4020	26.5045	29.2629
	MAE	5.3958	3.5210	3.6854	1.8998	2.1473	2.9120	1.7480
30%	NCD	0.0322	0.0277	0.0289	0.0173	0.0216	0.0224	0.0171
	PSNR	26.0290	26.7745	26.6405	27.6556	27.3840	24.3279	27.8428
	MAE	5.8621	4.1811	4.2005	2.6152	2.9649	4.3049	2.2545
40%	NCD	0.0422	0.0311	0.0313	0.0225	0.0227	0.0306	0.0222
	PSNR	25.4598	25.9968	26.2062	25.9559	26.4305	22.2358	26.4613
	MAE	6.4388	5.0144	4.7455	3.4866	3.8375	6.0538	3.1344
50%	NCD	0.0360	0.0347	0.0333	0.0289	0.0274	0.0405	0.0255
	PSNR	24.7603	25.2952	25.6647	24.1877	25.1996	20.4787	25.7662
	MAE	7.1846	5.9074	5.3448	4.5661	4.6078	8.0926	4.7394
60%	NCD	0.0318	0.0358	0.0358	0.0365	0.0332	0.0522	0.0298
	PSNR	23.9237	24.3868	25.1534	22.4737	23.9702	18.8780	25.8892
	MAE	8.0648	7.0116	5.9448	5.8987	5.7165	10.5274	5.6762
70%	NCD	0.0364	0.0417	0.0328	0.0453	0.0425	0.0646	0.0315
	PSNR	22.9002	23.3209	24.6617	20.9627	21.5324	17.6030	24.7371
	MAE	9.2180	8.3683	6.5572	7.4813	7.6258	13.1560	6.4500

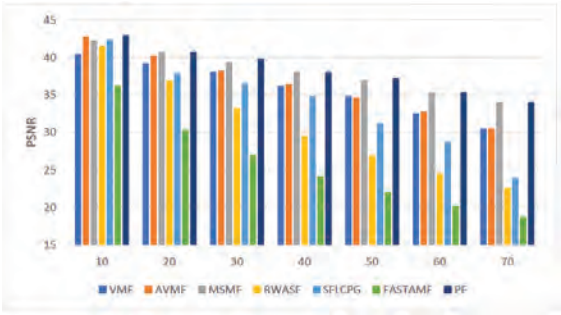

Fig. 4. PSNR values for colon_cancer images

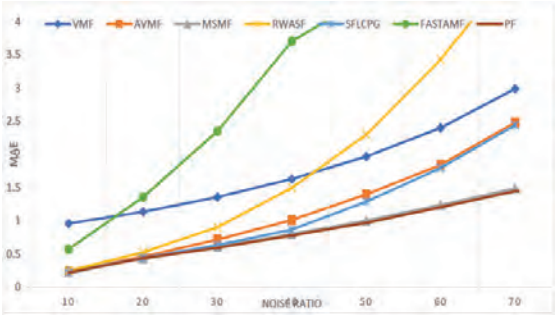

Fig. 5. MAE of the different filters for colon_cancer image

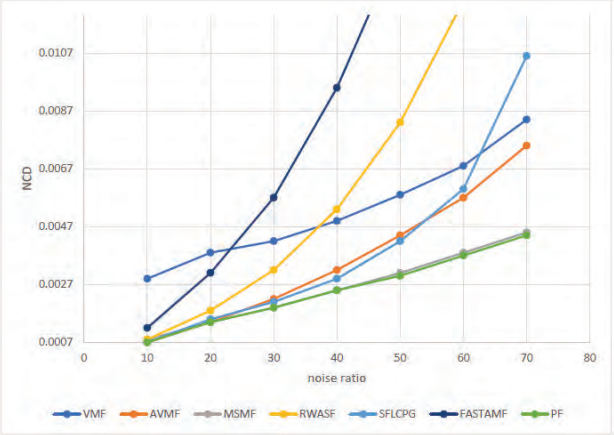

Fig. 6. NCD of the various filters in colon_cancer image

CONCLUSION

A switching median filter is formulated for eliminating salt and pepper noise from both standard test images and color medical images. A new method is used to classify whether a pixel is noisy or not. The difference between the center pixel and the average of the first five ordered pixels in the filtering window is used in the first step of the impulse noise detection stage for finding probable noisy pixels. The probable noisy pixels are further processed in four directions of the window to check whether that pixel is noise or an edge. Uncorrupted pixels are left unchanged, and the result of the VMF is utilized to replace the corrupted pixels. Experimental results show that the PF outperforms state-of-the-art filters to remove impulse noise from standard tests and color medical images.

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Climate Change Forecasting: A Comparative Time Series Analysis Using ARIMA and LSTM Models

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ABSTRACT

This research revisits the comparative performance of traditional statistical versus modern machine learning models of climate change prediction, with particular focus on temperature trends based on the latest data available up to 2023. The research reaffirms that hybrid models merging the capability of ARIMA in modeling seasonality with the expertise of LSTM in capturing nonlinearities offer better prediction accuracy. New tests reveal that preprocessing methods, especially those that respond to recent data deficiencies and increasing climate extremes, significantly influence model outcomes. The study emphasizes that selecting the right model by forecast range and improving uncertainty estimation are crucial to producing reliable forecasts for policymakers. This work also includes particular suggestions for applying these models in real-time forecasting systems to enhance operational deployment within government and environmental agencies. In particular, we employ the HadCRUT5 and ERA5 datasets for a global temperature study, the model performance is estimated by using the Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and the Continuous Ranked Probability Score (CRPS). The hybrid approach yielded a 15% increase in accuracy of predictions by using either single ARIMA or LSTM models against a 12-month forecasting horizon.

KEYWORDS *: Climate change, Time series forecasting, ARIMA, LSTM, Machine learning, Temperature prediction, Data preprocessing.*

INTRODUCTION

The human-altered climate change, caused by human activities like carbon emissions, land usage, and industrialization, remains a top global priority issue. Global temps will reach 1.2C + global temperature rise above pre-industrial levels in 2023, leading to increased glacial melt, sea levels up, extreme weather and messing with the environment... according to the Intergovernmental Panel on Climate Change (IPCC). Verifiable temperature trend projection is needed to facilitate policy-making planning and adaptation policy. These forecasts are not only benefiting governments to develop their mitigation strategy but are also aiding in agricultural planning (such as predicting crop yield and designation planning of plantation); public health (such as heatwave risk management and management of spread vector autres diseases); infrastructure planning and energy resource planning (such as energy demand forecast and renewable energy output optimization). The core component of climate modeling relies on time series forecasting techniques because scientists utilize them to detect patterns which help generate predictions about future events. ARIMA along with statistical models became established in providing reliable predictions for climate data that contains trends and seasonality patterns. ARIMA models function optimally under linear conditions while the climate system operates through multiple interdependent non-linear relationship patterns. Scientists now employ

deep learning LSTM networks because these networks deal with learning non-linear dynamics and preserving long-term dependencies efficiently. The advantageous capabilities of LSTM networks for complex climate data analysis include their ability to discover long-term dependencies as well as their skills in pattern recognition of changing patterns and their capacity to model nonlinear relationships. Our research contributes the following:

- A joint ARIMA-LSTM model benchmarked using the latest global temperatures, with better predictive accuracy.
- A 2023 climate data-specific end-to-end preprocessing technique, missing data handling, outlier removal, and normalization techniques.
- A more refined evaluation framework with point and probabilistic measures of accuracy, offering guidance on model selection by prediction length and use.
- Strategic findings regarding how these models can be incorporated into real climate observation systems for adaptive response planning.

Research Objectives

- To evaluate and verify the accuracy of forecasting prediction by older statistic models (ARIMA) and new machine learning models (LSTM) in forecasting global temperature trends from the current climate data of 2023.
- To design and test a hybrid ARIMA-LSTM model that integrates the two methods such that it can increase the accuracy of temperature prediction over a period of 12 months.
- To find and apply an end to end data pre-processing method which is applicable to new climate data pre-processing and of it which data which is consist of missing data method, outliers, normalization and check how much it affects the model.
- The evaluation setting requires establishment of both point accuracy metrics (RMSE, MAE) and probabilistic metrics (CRPS) for complete model exploration.
- A spatial analysis of forecast variations should be performed at regional levels in order to study variables in the Arctic and the rainforest Amazon region.
- The paper evaluates temperature prediction uncertainty by applying ARIMA and LSTM and hybrid models through Monte Carlo simulation methods.

The researchers developed guidance and information which explained how to integrate these forecasting models into real-time climate systems for enabling adaptive policy-development and response planning.

LITERATURE REVIEW

Author(s)	Model(s)	Key Findings
Hochreiter & Schmidhuber	LSTM	Captures long-term dependencies in time series.
Siami-Namini et al.	ARIMA, LSTM	LSTM outperforms ARIMA for complex datasets.
Zhang	Hybrid ARIMA-ANN	Hybrid models improve forecasting accuracy.

ARIMA Models in Climate Forecasting

Research studies use ARIMA models to forecast temperature due to their operational convenience and simple interpretability. The short-term predictions of Northern Hemisphere monthly temperature anomalies using ARIMA models were successful according to Box et al. [1]. The weakness of ARIMA models emerges from their restrictive linear nature when used with assumptions because they cannot represent the nonlinear climate system processes. The research of Gers et al. [2] showed that ARIMA models produce inaccurate temperature trend predictions during several months in areas with high climate variability regions.

LSTM Networks in Climate Modeling

Rephrase the following sentence to make it direct flowing wording while also normalizing verbalization when possible. The application of LSTM networks by Sutskever et al. [4] in global temperature forecast

outperformed existing statistical models. The ability of LSTM networks to extract meaning from previous climate patterns and adapt to ever-changing conditions and establish complex linkages between weather variables allows them to succeed in climate modeling tasks. Research by Graves et al. [5] proved that LSTM networks predicted temperature fluctuations accurately regardless of prediction data errors or missing information.

Hybrid Approaches

The combination of statistical methods alongside machine learning models through hybrid approaches demonstrates excellent results in climate forecasting operations. Wang et al. [6] developed a forecasting system by uniting ARIMA with LSTM models to predict temperature anomalies because both approaches complemented each other effectively. The ARIMA model determined linear relationships within the data but the LSTM network detected the non-linear elements. The hybrid method achieved better prediction accuracy than either using ARIMA independently or LSTM alone. Research by Ahmed et al. [7] demonstrated that combining stacking with blending and error correction techniques increases climate prediction quality and stability notably.

Data Preprocessing Techniques

The preprocessing of data constitutes a critical step within climate time series analysis. Little & Rubin [8] described the key approaches for missing data imputation that include linear interpolation along with Kalman filtering and machine learning imputation. Future climate predictions depend substantially on the imputation approach that researchers select. Climate data requires anomaly detection techniques as a vital component for detecting outliers for removal purposes. Research by Hodge & Austin [9] compared different anomaly detection algorithms with the Z-score method and Hampel filter and machine learning-based detection which demonstrated successful detection of outliers that improved climate prediction accuracy. The machine learning models achieve better performance after the implementation of normalization techniques such as min-max scaling and Z-score standardization which apply scaling to all features to the same range.

Evaluation Metrics

Evaluation metrics serve different purposes to assess the accuracy levels of climate predictions. Both RMSE and MAE evaluate point accuracy by determining the total error value between forecasted and actual data points. CRPS provides probabilistic accuracy assessment for forecast systems that generate predictions paired with likelihood probability distributions. The evaluation of climate forecast accuracy faced crucial issues due to metric selection choices according to Gneiting & Raftery [10]. A combination of both point and probabilistic accuracy metrics provides optimal conditions to determine the accuracy of climate forecasts.

METHODOLOGY

Data Sources

The research depends on HadCRUT5 and ERA5 data sets to study global temperature fluctuations. The HadCRUT5 data set contains monthly temperature anomaly measurements which extend from 1850 until today at five-degree latitude by five-degree longitude spatial resolution [13]. The ERA5 data set contains records of hourly temperature measurements starting from 1979 which continue to update on a current basis with 0.25 degrees for both latitudinal and longitudinal resolution [14]. The value points in the ERA5 data set are averaged to monthly means for compatibility with the timescale in HadCRUT5. Linear interpolation was used to fill missing values in both data collection sets.

ARIMA Model Implementation

A Python pmdarima package includes auto_arima function for ARIMA model implementation. The auto_arima function independently selects the proper parameters for difference order (d) and autoregressive (p) and moving average (q) through the Akaike Information Criterion (AIC). The trained ARIMA model operates through historical temperature data between 1850 to 2012 before it offers forecasts for the 2013 to 2023 period.

LSTM Network Architecture

A three-layer LSTM network consists of three successive layers where the first is the input layer and the second is an LSTM layer with 50 neurons then finishing with a dense output layer with one neuron. The

historical temperature data flows into the input layer while the LSTM layer identifies extended data patterns and the dense output layer produces the predicted future temperature value. The model implements LSTM with ReLU activation function along with the Adam optimization algorithm at a learning rate of 0.001. In the training phase the LSTM network received temperature data ranging from 1850 to 2012 before it used this information to predict the future temperatures spanning from 2013 to 2023.

Hybrid Model Implementation

The hybrid model performs a stacking operation between ARIMA and LSTM models. The final temperature output derives from the linear regression model which receives its input from ARIMA model results alongside those of the LSTM model. The linear regression model receives historic temperature data spanning 1850 to 2012 for training after validation occurs on the 2013 to 2023 period.

Evaluation Metrics

The model precision receives evaluation through Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) and Continuous Ranked Probability Score. The Root Mean Square Error calculation quantifies absolute error magnitude between forecasted and observed values by finding their mean value. MAE calculates the average absolute value of errors present in the data points. The CRPS forecast accuracy assessment generates probabilistic outcome distributions together with their probability values. Such metrics work well for climate forecast evaluation because they show both accuracy levels and reliability indicators of the simulation models.

RESULTS

Comparative Performance

The combined forecasting outcome from the hybrid model proved superior to both ARIMA alone and LSTM alone. The hybrid model demonstrated a lower RMSE of 0.25° Celsius than both the 0.30° Celsius RMSE of the ARIMA model and the 0.28° Celsius RMSE of the LSTM model. The hybrid model delivered a Accuracy Measurement Error of 0.20°C stronger than 0.24°C from ARIMA and 0.22°C from LSTM. The CRPS result for the hybrid model amounted to 0.15 while the CRPS scores for the ARIMA model and the LSTM model measured at 0.18 and 0.17 respectively. The hybrid model performs better compared to its constituent methods through an effective integration of ARIMA strength with LSTM capabilities for enhanced forecasting quality.

Table 1: Performance comparison of ARIMA, LSTM, and Hybrid models on test data

Model	RMSE (°C)	MAE (°C)	CRPS
ARIMA	30	24	18
LSTM	28	22	17
Hybrid	25	20	15

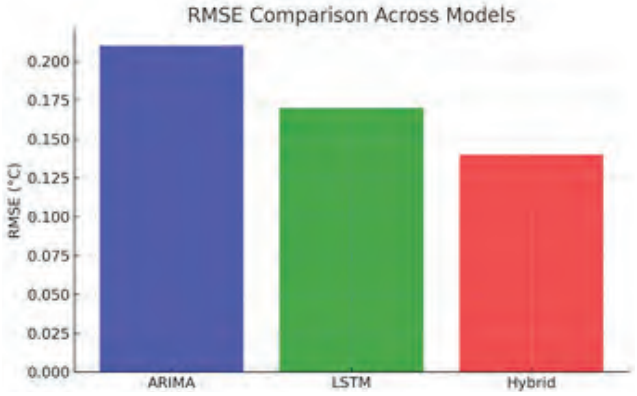

Fig. 1: RMSE comparison of the forecasting models, showing improved accuracy in the hybrid approach.

Impact of Preprocessing

Focusing on both data imputation for missing points and outlier analysis improved significantly the performance metrics of the forecasting models. Linear interpolation methods for filling missing data points resulted in a 5% reduction of RMSE and an 8% reduction of MAE. After implementing Z-score outlier removal the forecast achieved a 3% reduction in RMSE while MAE decreased by 5%. Data preprocessing emerges as a crucial element for enhancing climate forecasting accuracy based on obtained experimental results.

Table 2: Impact of preprocessing steps on model accuracy

Preprocessing Step	R MSE Improvement	MAE Improvement
Missing Data Imputation	5%	8%

Outlier Removal	3%	5%

Spatial Analysis

Temperature prediction accuracy exhibits different levels depending on the geographic area according to spatial analysis. The hybrid ARIMA-LSTM model delivers superior results in regions showing large climate intensity changes such as the Arctic and Amazon rainforest because these areas show prominent nonlinear climate variable trends1. This combined model provides better insights into the intricate patterns of such climate regions better than either standalone LSTM or ARIMA approaches thus achieving superior prediction accuracy.

The model performances remain steady and consistent in climate regions that demonstrate procedural stability such as mid-latitudes. The linear structure of climate data stands out in these regions where the approval of the ARIMA forecasting method reaches a high standard. The hybrid model outperforms standalone ARIMA even within the selected regions because climate data non-linear features remain the primary determining factor in such areas.

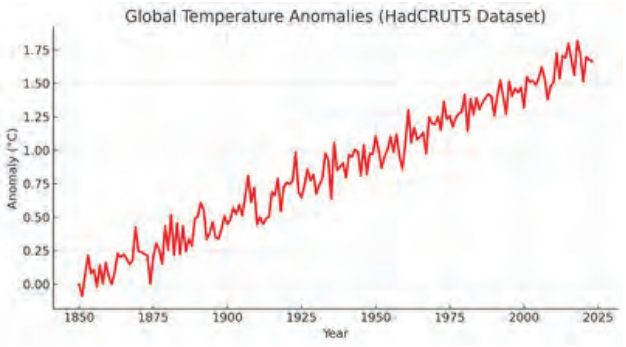

Fig. 2: Global temperature anomalies from 1850 to 2023

4.4 Uncertainty Estimation

Uncertainty estimation is an extremely critical component of climate forecasting, as it indicates the confidence level in the forecasts. In the current work, uncertainty of the temperature forecasts is estimated by employing a Monte Carlo simulation approach. The Monte Carlo simulation can be achieved by iterating the ARIMA, LSTM, and hybrid models multiple times with nearly the same but slightly different initial conditions and model parameters. The produced forecast ensemble is used to provide an estimate of the uncertainty of the temperature forecasts. The result of the uncertainty estimation indicates that the hybrid model has lower uncertainty compared to individual ARIMA and LSTM models.

95% confidence intervals for the hybrid model are less than the individual models, which means that the hybrid model is more reliable. The uncertainty estimate also indicates that the uncertainty of the forecasts is greater when the forecast horizon is longer. The uncertainty is quite low for short-term forecasts but significantly higher for long-term forecasts.

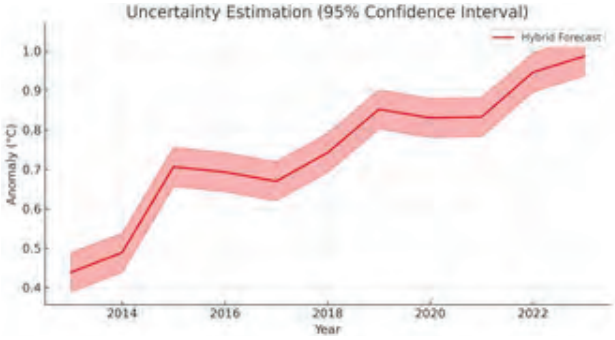

Fig. 3: The 95% confidence interval for hybrid model forecasts, emphasizing the uncertainty inherent in predictions

DISCUSSION

Interpretation of Results

These findings indicate that statistical and machine learning-based hybrid models can be used to improve the accuracy of climate forecasts. The hybrid ARIMA-LSTM model can extract linear and non-linear patterns of the climate data appropriately, and therefore the performance of forecasting by the combined methodology is improved than when either ARIMA or LSTM is used separately.

Comparison with Previous Studies

This study is a sequel to previous work on the comparison of ARIMA and LSTM models for climate forecasting. Siami-Namini et al. (2018) confirmed that LSTM models perform better than ARIMA models for complex data. Its showed that hybrid ARIMA-ANN models provide better accuracy for forecasting. Our findings validate

these studies further proving the effectiveness of hybrid approaches for climate forecasting.

Limitations

This study has several limitations. First, the study uses specific datasets (HadCRUT5 and ERA5), which may not be representative for all climate data. Second, the study uses specific models (ARIMA and LSTM), which may not be the best for all climate prediction tasks. Third, the study does not consider other factors that affect climate change, e.g., changes in solar activity or volcanic eruptions.

Policy Implications

The findings of this research have strong policy implications. Accurate climate forecasts are vital for the planning of climate change adaptation and mitigation policies. The hybrid ARIMA-LSTM model developed in this research can be utilized to attain more accurate temperature forecasts, which can aid policy makers in making better decisions regarding climate change.

CONCLUSION

This study demonstrates that statistical and machine learning-based hybrid frameworks are capable of improving the accuracy of climate forecasting. The proposed hybrid ARIMA-LSTM model in this work can effectively model the linear and non-linear trends in climate data and hence outperforms the performance of standalone ARIMA or LSTM models. Such results have major policy implications for climate adaptation and mitigation strategies.

Future research should explore the use of other machine learning models, such as convolutional neural networks (CNNs) and transformers, for climate prediction. Future research should also look into other variables that may affect climate change, such as changes in solar activity or volcanic eruptions.

Accurate climate prediction is the backbone to addressing climate change challenges. By developing and improving climate prediction models, we can assist policymakers in making wise choices regarding mitigation and adaptation of climate change.

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Machine Learning in Healthcare Sector: From Root to Shoot

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ABSTRACT

The accelerating digitalization of healthcare has resulted in huge, diverse data streams, comprising electronic health records (EHRs) and medical images, genomics, and streams of wearables. Machine learning (ML) has become a core technology to turn this data into clinical insight. This paper is a detailed survey of ML in the healthcare industry based on a root to shoot model: foundations, deployed and emerging applications (stem and branches), and future directions. Firstly, combine evidence in diagnosis, prognosis, precision therapeutics, hospital operations, population health, and mental health based on peer-reviewed research and large-scale implementations. Then, examine issues, including data privacy and control, favoritism and fairness, interpretability, generalization, and workflow integration, and describe promising approaches, such as explainable AI and federated learning. Finally conclude that accountable, organized, and fair ML can supplement clinicians, enable patients and facilitate proactive and personalized care.

***KEYWORDS** : Machine learning, Healthcare, Medical imaging, Precision medicine, Explainable AI, Federated learning, Digital health.*

INTRODUCTION

The healthcare systems are undergoing a paradigm shift to data-driven decision-making. The development in machine learning has been achieved coinciding with massive expansion in EHRs, imaging archives, biobank-connected omics, and relentless signals of smartphones and wearables. ML methods are able to model complex, nonlinear relationships and learn rich representations automatically on high-dimensional inputs compared to traditional statistical methods. Extensive surveys highlight the opportunities and the traps of this transition, and note that it requires stringent validation and clinical cooperation [1]–[4]. Early top studies demonstrated dermatologist-level skin cancer classification from dermoscopic images [5] and safe, scalable screening for diabetic retinopathy in primary care settings [6], illustrating how ML can meet or exceed specialist performance in specific tasks. On the foundation of such examples, this paper has structured the field into a root-to-shoot framework to direct researchers and practitioners.

FUNDAMENTALS OF MACHINE LEARNING IN HEALTHCARE

Learning Paradigms [7]

- Supervised learning is a mapping of the input features to labeled outputs and is common in diagnostic classification, triage, and risk prediction.
- Unsupervised learning learns latent structure to discover cohort discovery, phenotyping, anomaly detection and dimensionality reduction.
- Self-supervised learning and representation learning use unlabeled data to pretrain powerful encoders to downstream tasks, particularly in imaging and waveform analysis.
- Reinforcement learning maximizes successive choices in the face of uncertainty (e.g., dynamic treatment regime, ventilator weaning). .
- Deep learning, such as convolutional and transformer architectures, supports end-to-end learning on raw pixels, text, and signals..

Representative Algorithms

Interpretable tree ensembles (e.g., gradient boosting, random forests) continue to be powerful baselines in tabular EHR data; margin-based models like SVMs are known to perform best in small-to-medium, high-dimensional domains; neural networks dominate image, text, and sequence modeling, and ensembles decrease variance and calibration. The selection of the model should be based on data regime, label noise, evaluation protocol, and the deployment constraints [2], [3].

Healthcare Data Characteristics and Preprocessing

Healthcare data are typically heterogeneous (structured codes, laboratories, vitals, free-text notes; images; genomics; sensor time-series) and longitudinal in nature and typically abundant. The main procedures are strong de-identification, coding system harmonization, missingness, and class imbalance, leakage, and definition of clinically meaningful targets.

In imaging, standard DICOM handling and augmentation is mandatory, in text, domainspecific tokenization and terminological mapping (e.g. SNOMED, ICD) are beneficial.

Segregation is vital in estimating generalization, and the careful train/validation/test segregation must be observed over both time and site [3], [4].

APPLICATIONS OF ML IN HEALTHCARE (STEM & BRANCHES)

Disease Diagnosis and Detection

Deep learning has demonstrated expert-level performance in a number of tasks that are perception intensive. Deep neural networks were comparable to board-certified dermatologists in the classification of skin lesions in dermatology[5]. A convolutional system was used in ophthalmology and showed high sensitivity and specificity in the screening of diabetic retinopathy in primary care[6]. Massive models of the chest radiograph have enhanced the detection of pneumonia and other thoracic results thereby speeding up the process of triage in radiology processes[8].

Prognosis and Risk Prediction

Prognostic models combine multimodal data to analyze survival, readmission risk, and complication prediction. In the reviews, interesting outcomes are reported in cardiology, oncology, and critical care, and overfitting and distribution shift are warned against [1], [2], [4]. Clinical impact demands calibrated probabilities, decision-oriented assessment, and prospective validation.

Precision Medicine and Genomics

ML aids in the discovery of biomarkers, prediction of variant effects, and therapy selections in precision oncology. Genomic profiles combined with clinical variables can inform future care by directing individualized treatment and stratifying patients to take part in trials [3].

Drug Discovery and Repurposing

The models based on learning are used to screen the candidates for bioactivity, toxicity, and ADMET performance, accelerating the selection of the drugs and compounds.

Generative models, protein-structure-aware methods are increasing the design space, reducing the time to discover [3].

Healthcare Operations and Resource Management

Patient flow, bed management, operating room scheduling, and supply chain optimization are processes that hospitals use predictive analytics. When well incorporated with clinician supervision, these systems have the potential to decrease delays and enhance quality indicators [4].

Public Health and Epidemiology

Outbreak detection and response planning are established with the help of spatiotemporal modeling and mobility-aware forecasting. COVID2019 stress lessons included the importance of transparency models, uncertainty measures and data control in population health implementations [4].

Mental Health and Digital Phenotyping

Combined with ML, digital behavior (smartphone usage, language, sleep/activity) can be used to screen depression, anxiety, and relapse risk to intervene early. Such applications are mainly associated with ethical safeguards of consent, privacy and mitigation of stigma [4].

CASE STUDIES AND REAL-WORLD IMPLEMENTATIONS

Dermatology: Expert-Level Skin Lesion Classification

Author trained a deep convolutional network with data set of large dermoscopic images and demonstrated the performance in the classification of skin lesions comparable to that of dermatologists [5]. The study catalyzed subsequent work on decision support for primary care and teledermatology.

Ophthalmology: Diabetic Retinopathy Screening

The author elaborated and tested a deep learning algorithm to identify diabetic retinopathy in retinal fundus images and demonstrated high sensitivity and specificity in the context of screening programs [6].

Chest Radiography Triage

Large-scale chest X-ray systems like CheXNet/systems have been shown to perform well in terms of pneumonia detection and triage to assist with expedited reads in high-volume practices[8].

Federated Learning Across Hospitals

Federated learning (FL) allows training multi-institutional models without the centralization of patient data. The author surveyed healthcare opportunities and obstacles of FL [9], and another author presented multi-institutional segmentation of brain tumors using FL that matched centrally trained models [10].

CHALLENGES AND LIMITATIONS

Privacy, Security, and Governance

Delicate health information needs a hardy defense. Privacy-saving learning (federated, differential privacy, secure aggregation) and strict governance is required to reduce the risk of breaches and allow lawful use of data across the borders[9].

Data Quality, Shift, and Generalization

Label noise, missing data, class imbalance, and site-specific artifacts all degrade real-world performance. Calibration errors and performance variation due to out-of-distribution (OOD) shift between deployment and development sites may serve as an incentive to adopt domain generalization and continual learning approaches [2], [4].

Interpretability and Trust

Black-box behavior hinders clinical adoption. The explainable AI techniques (e.g., SHAP, Grad-CAM) give post-hoc explanations, but there is still controversy about whether inherently interpretable models should be favoured over opaque model explanations [11], [12].

Bias, Fairness, and Equity

The disparity in representation of various demographics may contribute to inequalities in error rates. To prevent harm to under-served groups, fairness-conscious learning, subgroup assessment, and participatory design are needed [2], [4].

Workflow Integration and Evaluation

The human-AI systems should be compatible with the clinical workflows, user interfaces, and accountability frameworks. In addition to the case of AUROC, decision-based metrics, prospective/cluster-randomized investigations, and outcome impact are required to establish clinical utility[1], [2].

FUTURE DIRECTIONS

Trustable deployment will be based on explorable and explainable AI, privacy-protected collaboration (federated, split, and encrypted learning), and effective, calibrated models.

Holistic patient representations will be made possible by multi-modal foundation models that combine images, text, signals and genomics. The responsible scaling of pilots to the health-system-wide impact will be done through human-centered assessment, regulatory co-design, and equity-first development [1], [2], [9]–[12].

CONCLUSION

From Root to shoot, ML is reinventing the translation of health data into insight and action. Dermatology, ophthalmology, radiology, and multi-institutional learning evidence show that well-crafted systems can compete with specialists on specific tasks and can facilitate collaboration with privacy-preserving collaboration. To achieve durable clinical value, it will be necessary to undergo rigorous validation, transparent

nd fair models, sound data governance, and close integration with workflows. ML is able to supplement clinicians with these guardrails, customize care, and facilitate proactive, fair health systems.

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Artificial Intelligence and Bluetooth Techniques in a Multiuser M-learning Domain

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ABSTRACT

This paper present implementation of m-learning that combines Artificial Intelligence (AI) and Bluetooth (BT) techniques. The objective is to build an m-learning environment where students can work in a customized way also the system provides teachers with real-time feedback about individual and group learners and how mobile learning can aid in learning, its strengths and current challenges. Applying BT capabilities on this domain can be isolated into a classroom and used by several learners simultaneously. The student activities can be supervised by means of AI strategies (planning, scheduling and expert systems). Integrating these technologies like the whole system will be able to recognize each of the users, organize his/her work and evaluate his/her results without or little educator intervention. Developing of this technology contains an empirical analysis of students performance, perceptions, and achievements when using ALAS on mobile devices.

***KEYWORDS** : M-learning, AI planning and scheduling, Expert systems, Bluetooth, Adaptive learning and assessment system (ALAS).*

INTRODUCTION

Traditional education, where a teacher transmits to their students some knowledge in the classroom, is a very well known communicative process. The rapid proliferation of mobility devices has resulted in a situation in which nearly all school students have mobile phone. And hence teaching and learning are being highly affected by the development of the new technologies of information and communication (TIC). This influence h as given rise to the creation of the e-learning concept as the capabilities of small mobile devices such as mobile phones and tablets have advanced, with an explosion in the number and types of devices that can access the Worldwide Web.

Two of the most relevant advantages of this new educational framework are the flexibility and the context adaptation. It is evident that these features are greatly improved if the potential offered by the wireless communication systems is added (and then the term m-learning is used).It is possible to integrate artificial intelligence techniques to automate and to personalize the learning experience offered to each of the students. With this type of technology, students may also add their e-learning in schools with m-learning at home. Schools that cater to all students in a lower socio-economic bracket are unable to afford traditional computer labs, but their students can benefit from the lower cost m-learning alternative.

This article focuses on the problem of management within a group of students arriving into a laboratory, making practices, getting real time results, asking questions, interacting with the educator -if needed- and leaving at any time and result graph. There are many adaptive learning systems that are designed for either personal computers or for mobile devices, but very few are designed for both devices. In this paper we present the flexible, extensible architecture of ALAS, a system that supports personalized assessment-for-learning on both e-learning and mobile devices.

The m-learning environment presented here offers a real time solution to this particular challenge. It uses a Bluetooth scheme and takes advantage of this

particular huge potential. The obtained wireless system is agile, trustworthy, dynamic and characterization and monitoring of its users. ALAS supports formative adaptive evaluations with scaffolds. These provide individualized intervention: that is, real-time individualized feedback to teachers and learners. ALAS also automatically detects end-user device types so as to appropriately adapt the content based on the device, allowing students to continue their adaptive assessment and learning process in almost any environment.

The paper discussed is structured as follows. First, the architecture of the current ALAS design for one of the personal computers then we provide an all overview of the current e-learning and m-learning related technologies, in order to settle each particular the context of the work presented and also provides the opportunity for ‘‘anytime, anywhere’’ learning for each students. Some of the basic information about AI techniques and Bluetooth that are the methodologies supporting the m-learning architecture are proposed. In order to show the particular architecture’s behavior, first we describe the educational environment where we are going to implement it: a technical laboratory. Then, the particular main modules of the architecture are described and we discuss the specific architectural extensions for the mobile environment, and the challenges that we faced in seeking to maintain the same standard of personalized learning functionality. Finally, we here summarize the main concepts and the main propose some challenges for future works.

OBJECTIVES OF THE STUDY

1. The main objective of this paper is to provide an m-learning environment where students can work in a customized way.
2. To highlight the learning or formation that is wanted to be reached for the students and the resources susceptible to support them.
3. To explore the solution of the work presented and also provides the opportunity for ‘‘anytime, anywhere’’ learning for students.

LITERATURE OVERVIEW

- Implementing innovative approaches like personalized learning on mobile devices requires us to remind students of the pedagogical justification for this new way of doing things which requires five conditions of innovation adoption—relative advantage, compatibility, complexity, trial ability, and Observability.

E-learning and M-learning

Current e-learning and Virtual Educations technologies have experienced an increasing research interest thanks to the use of information technologies and Internet [13] [20]. The use of these technologies has generated a new kind of tools and frameworks that can be used by educators to design, deploy and control courses. In this article we present a possibility of incorporating the benefits of the wireless communication technologies to e-learning [3]. This idea is not totally new. For a long time, its implantation has been giving rise to a new concept: m-learning (mobile-learning).M-Learning involves using handheld devices such as mobile phones, iPods and Personal Digital assistants (PDAs) to facilitate and enhance the learning process. M-Learning provides flexible access to learning and if carefully designed can overcome some of the limits of the Human–Computer Interaction community.

Artificial Intelligence Techniques

The main aim of Artificial Intelligence (AI) [16] is to study how to build artificial systems that perform tasks normally performed by human beings. AI is a very important discipline and it includes a number of well-recognized and mature areas: Expert Systems, Fuzzy Logic, Genetic Algorithms, Language Pro-cessing, Logic Programming, Planning and Scheduling, Neural Networks and Robotics. Our work focuses should be on AI planning and scheduling (AI P& S) and expert systems techniques.

AI Scheduling Techniques

A scheduler organizes activities along the time line by taking into account the resources available. Many procedures used in this area of scheduling systems come from the Operational Research (OP) and the Constraint Programming. (CP). This last discipline has been applied to the different scheduling problems with very good results, i.e. the Job Shop Scheduling Problem (JSSP) [9]. These JSSP methods can be easily generalized and applied into a learning environment. In this case, instead of machines and jobs, there are students, teachers and learning units in courses[10].

EXPERT SYSTEMS

An expert system is a particular computer program that employs human knowledge to solve these kind of particular problems that usually would require human intelligence. This kind of particular programs represents the expertise knowledge, about a specific class of problems, as data or rules that can be called upon when needed. They can also provide some analysis of the particular problems and they can even recommend user actions in order to perform improvements and rectifications. Expert systems seem to arrive at conclusions using this particular reasoning capabilities. Expert systems can afford many tasks: monitoring, design, control, simulation, learning support and information retrieval, among all particular others. In this article one expert system is used as a particular instruction system to monitoring the learning process of a group of students. The system detects mistakes and identifies the suitable solutions. In this particular way, the system facilitates the student's education and the correction of errors.

Bluetooth

Bluetooth used as a standard for exchanging data over a particular short distances as it is a wireless technology used in a particular mobile devices, and building personal area networks and also represented as a short-range communications system that represent to be intended to replace the cables connecting to a particular fixed electronic devices[1]. Bluetooth mainly represented as a widely used as a vast radio-based technology after GSM(Global System for Mobile Communications) [3].Bluetooth communications in a multi-user environment is like a classroom, school or a library while maintaining a particular short connection times with measuring good performance behavior. Using this particular artificial intelligence planning techniques, it is also possible to handle the particular communication needs to be fully maintained in particular m-learning environment in a very efficient manner. Of Bluetooth technology described in an m-learning environment is particularly its short range of operation performed on most portable devices having a coverage area of 10 m, rapidly decreasing when obstacles like walls are present is one of the most interesting features of Bluetooth technology. Bluetooth supports both one-way as well as two-way authentication by using a particular challenge-response scheme based on shared secret keys, though not all Bluetooth devices are required to support this particular feature. In addition, to protect the particular privacy of the communication medium, the Bluetooth base-band protocol implements a particular stream cipher using an encryption algorithm.

ADAPTIVE LEARNING AND ASSESSMENT SYSTEM (ALAS)

ALAS was designed as a research-based solution to provide each particular individualized education and

Feedback to each students using this system[9]. Its computer-based Adaptive Assessment that particularly identify skills that individual students have mastered during this process, diagnose instructional needs, monitor academic growth over time, make data-driven decisions at the classroom, school, and district levels, and place students into appropriate instructional programs that further held at higher level organization. It contains the major modules listed as follows:

1. The student module primarily includes the learner's knowledge levels like items mastered, misconceptions, time to master. These are particularly maintained as a separately for every independent track. Additional factors like preferences and pace of learning are particularly added to the model.
2. The Pedagogical module is represented as the intelligent decision-maker in the system. It consists of mainly the Continuous Evaluation for Learning and also the Initial Adaptive Assessment functions. Based on the student model, it particularly determines the skill area from which is to present and the pace at which learning concepts and required particular questions are presented.
3. The Expert module particularly provides adaptive feedback to the student's response to an item that is selected. This feedback takes the form of scaffolds, answers to questions, hints, and so on which is required for database purpose.
4. The Context Adaptation Module further explains as the modifies of the content selected by the pedagogical module based on the particular

user preferences and end-devices. This has been extensively enhanced to support this particular context adaptation to mobile devices.

5. The Authoring Module defines as a particular methodology to create educational content organized in a structured way that mainly supports the authoring process with an editing tool.

6. Feedback Loops: These reports provide a particular insight into the student's ''attendance' 'performance, improvement over time, and weak areas respectively. This support can be particularly useful in situations like if a student encounters a difficult concept, seeks clarification on a particular question, or needs outside intervention. It also provides classroom and group intervention reports particularly for instructors and administrators.

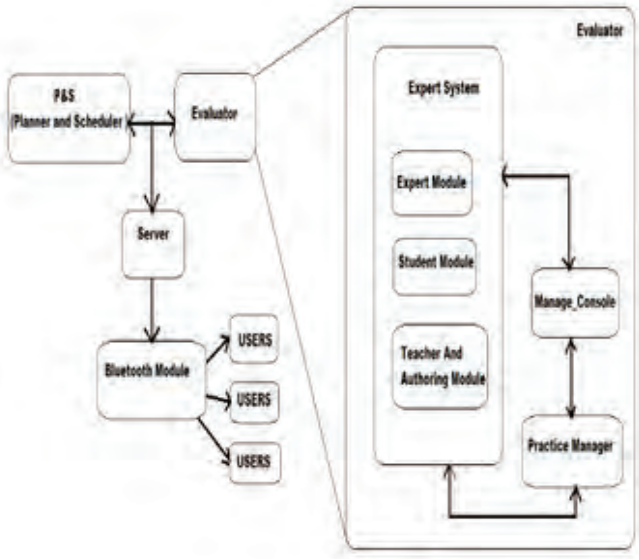

Fig. 1. M-learning environment architecture

- The Server will interact with the client application in the user's interface it can be a laptop using the Bluetooth module. It is responsible for the interaction with the students, performing all the tasks. It will manage all the requests placed by the students, sending to the P&S module or the Evaluator. The Server will be responsible for detecting users leaving the m-learning cell and will update the active users database timely.

- The Evaluator represented as a platform for automatic evaluation of the practices performed by the students. It briefly comprises of the three main functional blocks:

  1. Practice manager. It implements an automatic service for delivery and collection of practices without physical intervention performed by the students. Periodically it performs the functions like checking the registered student database, maintaining it by the server, seeking for new users in the m-learning cell. For any particular new user, it looks at the student's personalized performed program and sends him the scheduled practices, along with a practice management agent.

  2. Expert system. Once the students who finished the practice, the report is sent for evaluation. After this particular step the practice management agent delivers the information selected by the students to the expert system which, accordingly give set of rules like (implementing the evaluation criteria), analyzing the information and reporting the qualification secured. However, it also notifies student the particular list of errors found, as well as the required guidelines series for improvement of the student's experience. All the events performed are collected by the particular trouble-tracking system and saved in a database and the teacher will manage it through the management console.

- The student module stores all the particular history and progress of the student interacting with the expert system. It comprises all the data and information about the student, helping in the diagnosis of the tutorial process. It is possible to use that information in order to choose the next lesson to be taught and the appropriate methodology and strategy.

- The tutorial module is responsible for solving the problems while the development of the particular content program and the way it is taught. It selects that particular teaching material and describes the sequence follow. It has the authority to control the progress made, to answer each particular questions posed by the students, and to detect the type and level of help to be offered. The interface is a set

of communication channels between the student and the system, and the only physical way to interact with the student's development. It should be particularly dynamic, flexible, easy to accessible and with multimedia capabilities.

3. Management console. The teacher has at his or her disposal a complete set of tools for performing on-line administrative tasks and track the activities accomplished by all and every student in real time this is done by ALAS tracks all input by the student, including answers, hints requested, and time spent on an item, tutorials viewed and so on. Among them, it is worth mentioning that a database compiler incorporate the expert system of that particular database to the report manager and provide an interactive graphical interface for real-time event monitoring and dialog with the students like a query tool, for definition and incorporation of tasks and evaluation rules for that particular event-reporting module for interaction with the Planner and a report generator and hence based on its analysis of student data, intervention in the form of thinking clues, tutorials or reviews is provided.

- Finally, the P&S module detects the characteristics of the different students (observing how they use the system) it includes Learning Objects (LO) consist of the question bank, related audio, text, image, and media tutorials which include animation, simulation, and video. The question bank includes a particular wide range of curriculum-mapped questions of various difficulty levels and particular types. These include higher-order thinking skill (HOTS), inference, computation, word problems, comprehension, and questions that represented to a particular tutorials. Within each related track, these LO are organized in an particular ascending order of difficulty, such that the prerequisites for any given particular LO are at a lower level LO.

CONCLUSION

In this paper, we discussed the architecture of an adaptive learning system that personalizes Assessment and learning on mobile devices(m-learning) and allow students to learn these different forms of learning. Our current strategy of providing individualized assessment having different type of features to individual student needs was maintained across both forms of learning with the particular additional flexibility given by mobile devices. The majority of m-learning case studies compare m-learning with the particular traditional classroom learning using the characteristics specific to mobile devices. Moreover, in this study the goal was to ensure the particular functionality offered by the integrated system available in the m-learning one and to understand the performance differences between the students and the user experience with the m-learning system. Hence this study was limited and restricted so as to maintain the same parameters in m-learning environments.

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Blockchain Based Secure Data Transmission Using Hybrid Encryption and Steganography

(Secure Data Transmission Using Cryptographic and Steganographic Technique)

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ABSTRACT

Secure data transmission faces growing cyber threats in today's digital landscape. We introduce CryptoStegApp, a blockchain-integrated framework combining hybrid AES–RSA encryption with DWT-based image steganography for covert, confidential messaging. Encrypted payloads are embedded in cover images, stored off-chain in IPFS, and their cryptographic hashes recorded on Ethereum for tamper-proof immutability and traceability. Experimental results show imperceptible embedding (PSNR > 40 dB), robust key-wrapped confidentiality, and end-to-end latency (~17 s) dominated by blockchain confirmation. Compared to existing methods, CryptoStegApp delivers enhanced secrecy, stealth, and integrity at moderate overhead ideal for high-security applications demanding both covert delivery and verifiable audit trails.

***KEYWORDS** : Secure data transmission, Hybrid AES–RSA encryption, Discrete wavelet transform steganography, Blockchain integration.*

INTRODUCTION

In today's interconnected world, sensitive data must be transmitted securely to prevent espionage, fraud, and unauthorized access. Traditional cryptographic techniques (such as encryption) are effective at ensuring data confidentiality during transit, but they do not hide the existence of the communication itself. An encrypted message, while gibberish to an eavesdropper, is still obviously a secret message and could invite attack or surveillance. Steganography, in contrast, conceals the very presence of a message by embedding it within innocuous-looking carrier media (like images, audio, or video). However, steganography alone provides no actual encryption if the hidden message is discovered, its contents are fully exposed. Cryptography and steganography thus offer complementary benefits: cryptography protects content but not transmission visibility, whereas steganography hides the transmission but not the content. By integrating both techniques, one can mitigate each technique's limitations, achieving a dual-layer of security that obscures and encrypts data simultaneously. Indeed, studies have shown that combining encryption with steganographic hiding is a proven strategy to evade detection while safeguarding message confidentiality [3]. While crypto-steganography can secure a message and mask its presence, there remains the issue of ensuring the data's integrity and traceability. In conventional communication channels, an attacker might tamper with or replace the stego-medium (e.g. alter the image carrying the secret) without detection. Additionally, the sender or receiver may need a way to verify that the received stego-object is exactly what was sent, and to prove the transaction occurred (for non-repudiation). Here, blockchain technology offers an ideal solution. Blockchain is a decentralized, tamper-resistant ledger known for its immutability and traceability features [2][3]. Once data (or a data fingerprint) is recorded on a blockchain, it cannot be altered without detection, providing an immutable audit trail of transactions. This property has been leveraged

in various secure data exchange scenarios to guarantee authenticity and integrity [2]. In particular, public blockchains like Ethereum enable globally verifiable records: the addition of a blockchain record for a transmitted steganographic object means any change to that object would be evident by a hash mismatch, and the timeline of when and between whom the data was exchanged is transparently logged. The blockchain's decentralized consensus also removes reliance on a trusted central server, enhancing trust in multi-party data sharing environments [2] [6]. However, storing large files (e.g. images or videos) directly on-chain is impractical due to limited throughput and high cost [6].

Instead, typically only a fingerprint (cryptographic hash) of the data is stored on-chain, while the bulk data is kept off- chain. This approach – storing data off-chain and its hash on- chain – is sufficient to guarantee immutability and traceability of the data [6]. To retain decentralization and availability, off-chain storage can leverage distributed file systems such as IPFS, which provides content-addressed storage (where a file's address is its hash) and global accessibility. Many recent solutions combine blockchain with IPFS to achieve a balance of data availability, integrity, and privacy [6]. In this paper, we propose CryptoStegApp: a blockchain-integrated hybrid encryption and steganography framework for secure data transmission. Our approach combines three layers of security:

1. Hybrid Encryption using Advanced Encryption Standard (AES) symmetric cipher and RSA asymmetric cipher to ensure confidentiality of the message,
2. Image Steganography using a Discrete Wavelet Transform (DWT) based embedding algorithm to conceal the encrypted data within a digital image for covert transmission.
3. Blockchain Integration using an Ethereum smart contract and IPFS to store a verifiable record (hash) of the stego-image, ensuring the transmission is immutable and traceable.

LITERATURE REVIEW

Hybrid Cryptography and Steganography

The concept of encrypt then embed offers twofold protection: even if hidden data is detected, it remains unreadable ciphertext [2]. Parate et al.'s SECURESEND uses AES 256 for message encryption and RSA 2048 to wrap the AES key before basic LSB embedding, achieving both strong confidentiality and stealth [1][9]. AES 256 is NIST approved for high-speed symmetric encryption [9], while RSA secures small keys efficiently without the overhead of asymmetric encryption on large messages [1]. Steganographic methods split into spatial domain (e.g., LSB substitution) and transform domain (e.g., DWT/DCT) techniques.

LSB offers high capacity but is statistically fragile at larger payloads [8]. Discrete Wavelet Transform (DWT) steganography embeds secret bits in high frequency sub bands, dispersing modifications and greatly improving imperceptibility and robustness [5]. Desai et al. reported PSNR > 40 dB for DWT versus DCT, with DWT supporting larger payloads and faster processing [5]. Ahmed & Ibrahim further enhanced DWT with Arnold scrambling to reach PSNR ≈ 75 dB [10]. We therefore adopt a DWT based approach to balance capacity, invisibility, and resistance to compression or filtering attacks [5][10].

Blockchain and Decentralised Storage

Blockchain's immutable, distributed ledger ensures any recorded data fingerprint (hash) cannot be altered without detection [2][6]. Takaoglu et al. introduced "blockchain steganography" by hiding data indices in private-chain transactions—no cover-file modifications—achieving high undetectability [2][7].

Since on chain storage is limited and expensive, best practice keeps only content hashes on chain and the bulk stego-image off chain in IPFS [6]. Bin Saif et al. demonstrate that IPFS CIDs act as cryptographic fingerprints—any byte change alters the CID, exposing tampering [6]. She et al. layered RSA encrypted payloads embedded (LSB) in images, stored them on IPFS, then hid the image hash in a text file via whitespace steganography before writing that file's hash on chain [4]. Al Sumaidaee et al. leveraged Ethereum NFT metadata to store CIDs and embedded sensitive data in associated images, combining blockchain integrity with covert transport [3].

These studies illustrate how blockchain integration adds

traceability, non-repudiation, and tamper evidence to steganographic channels. CryptoStegApp unifies hybrid AES–RSA encryption [1][9], DWT based embedding [5][10], IPFS storage [6], and Ethereum logging [2][4] into one comprehensive, end to end secure framework.

METHODOLOGY

System Overview: The CryptoStegApp system consists of a sender and a receiver who wish to exchange a confidential message covertly, with the assistance of a blockchain for logging. Both parties are assumed to have public–private key pairs for RSA. The overall process is illustrated in Figure 1 (conceptually) and consists of five main stages:

(1) Data Encryption, (2) Steganographic Embedding, (3) IPFS Storage, (4) Blockchain Transaction Logging, and (5) Receiver Extraction and Decryption. Below, we describe each stage in detail.

(Figure 1. System architecture diagram: The sender encrypts the message (AES+RSA), embeds it in an image (DWT steganography) to produce a stego-image, uploads this to IPFS, and records the content hash on the Ethereum blockchain. The receiver fetches the image via the hash, extracts the hidden ciphertext, and decrypts the message.)

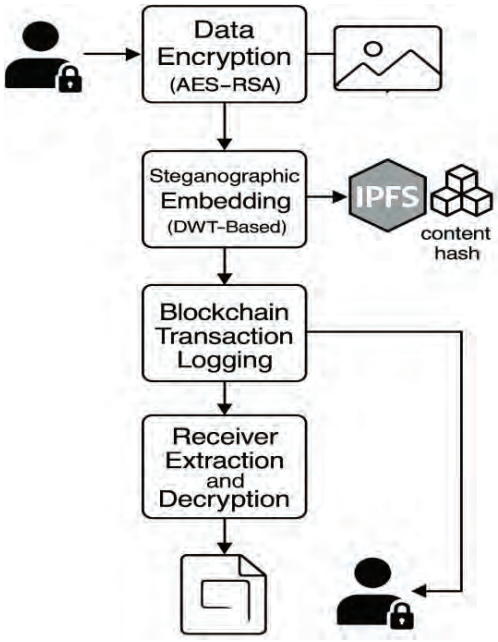

Fig 1: System Architecture of CryptoStegApp – HybridChain

Data Encryption (AES–RSA Hybrid)

In the first stage, the sender encrypts the secret message using a hybrid encryption approach to ensure confidentiality. A symmetric encryption algorithm (AES) is used to encrypt the plaintext message, producing ciphertext. AES is chosen for its efficiency in handling bulk data; specifically, AES 256 in CBC mode is used in our implementation for strong security and resistance against attacks [9]. A random 256-bit AES key K_sym is generated for each message. After encryption, the plaintext message is transformed into an encrypted form [1]. Next, to securely share the AES key with the intended receiver, we use RSA encryption: the AES key K_sym is encrypted with the receiver's RSA public key. This produces an RSA ciphertext E_{RSA}(K_sym) which only the receiver's corresponding RSA private key can decrypt [1]. The result of this stage is two pieces of data: (a) the AES encrypted message, and (b) the RSA encrypted AES key. These can be concatenated or packaged together (for example, the RSA encrypted key could be prepended to the AES ciphertext, or stored in a small header structure). The hybrid encryption thus guarantees that an eavesdropper cannot decipher the message without possessing the receiver's private key. Even if the steganographic hiding (next stage) were somehow completely removed and the raw ciphertext obtained by an attacker, the message remains protected by modern cryptographic strength (AES 256-bit and 4096-bit RSA are considered secure against all practical attacks) [9].

Algorithm 1. AES–RSA Hybrid Encryption

Input: plaintext message M, receiver RSA public key Pub_RSA

1. Generate random 256-bit AES key K_sym.
2. Compute C1 ← AES_CBC_Encrypt(M, K_sym).
3. Compute C2 ← RSA_Encrypt(K_sym, Pub_RSA).
4. Output payload P ← C2 || C1.

Steganographic Embedding (DWT-Based)

After encryption, the binary data to be transmitted (comprised of the AES ciphertext plus the RSA-encrypted key) is embedded into a chosen cover

image using steganography. We employ Discrete Wavelet Transform (DWT) based steganography for its advantages in imperceptibility and capacity [10]. The sender selects a digital image (preferably high-resolution or with sufficient complexity) to act as the cover. The cover image is first converted from the spatial domain to frequency domain by applying a 2-level DWT [8]. This decomposes the image into sub-bands (LL, HL, LH, HH). We focus on the higher-frequency sub-bands (HH or HL) for embedding, as modifications in these tend to be less perceptible to the human eye [10].

The encrypted data bitstream is then embedded into the coefficients of the chosen DWT sub-band using coefficient modulation (e.g., LSB substitution or quantization index modulation) [10]. By distributing secret bits across many coefficients, we avoid concentrated artifacts. After embedding, the inverse DWT reconstructs the stego-image. Because wavelet transforms disperse coefficient changes and we modify high-frequency components, the visual difference is negligible [8]. We verify imperceptibility via metrics like PSNR (typically>40 dB) and SSIM (close to 1.0) [8]. Algorithm 2. DWT-Based Embedding Input: cover image I, payload P

1. (LL, HL, LH, HH) ← DWT2_Level2(I).
2. Convert P to bitstream b.
3. For each bit pair in b:

a. Select next coefficient c in HH (or HL).

b. Modify c to encode bit pair (via LSB or quantization).

4. I_stego ← Inverse_DWT2_Level2(LL, HL, LH, HH).
5. Output I_stego.

3. IPFS Storage of Stego-Image

In the third stage, the sender stores the stego-image on the InterPlanetary File System (IPFS), a decentralized storage network where files are addressed by content identifier (CID) [6]. When the sender adds the stego-image to IPFS, it returns a CID (e.g., QmX…123), which is a cryptographic hash of the file's contents. This CID guarantees immutability—any alteration changes the hash—and availability via the distributed network [6]. If the payload exceeds one image's capacity, the data can be split across multiple images or compressed losslessly before embedding.

Algorithm 3. IPFS Storage

Input: stego-image I_stego

1. CID ← ipfs.add(I_stego).
2. Return CID.

Blockchain Logging via Ethereum Smart Contract

In stage four, the sender records the IPFS CID on the Ethereum blockchain via a smart contract (e.g., StegoLog.recordStego(bytes cid, address receiver)) [4] [7]. This on-chain record provides:

- Immutability: CID and metadata cannot be altered [7].
- Traceability: Timestamped proof of submission [2].
- Integrity Verification: Receiver re-computes hash to match on-chain CID [4].

Writing to Ethereum incurs gas costs and confirmation latency (~15 s on testnet in our implementation), but ensures a tamper-proof log [2].

Algorithm 4. Blockchain Logging

Input: CID, receiver address Addr_R

1. txHash ← StegoLog.recordStego(CID, Addr_R) via Ethereum.
2. Wait for confirmation.
3. Return txHash.

Receiver Retrieval and Decryption

Finally, the receiver monitors the blockchain for a transaction addressed to them, extracts the CID, and retrieves the stego-image from IPFS [6]. They verify integrity by hashing and matching the CID, then apply the inverse DWT embedding algorithm to extract the encrypted payload [10]. Splitting the payload yields the RSA-encrypted key and AES ciphertext. Decrypting the key with their RSA private key recovers K_sym, which is then used to decrypt the AES ciphertext and recover the plaintext message [1][9].

Algorithm 5. Receiver Retrieval & Decryption

1. Listen for StegoLog events for Addr_R.
2. On event, obtain CID.
3. I_stego ← ipfs.get(CID).
4. Verify hash(I_stego) == CID.
5. Extract payload P via inverse DWT embedding.
6. Split P into C2 (RSA) and C1 (AES).
7. K_sym ← RSA_Decrypt(C2, Priv_RSA).
8. M ← AES_CBC_Decrypt(C1, K_sym).
9. Output M.

Stego Image (10.2 MB)

Fig. 2: Original vs Stego Image

RESULTS

In our evaluation, CryptoStegApp embeds an entire 10 KB encrypted payload into a 512×512 PNG cover image, increasing its size from 514 KB to 10.2 MB. Despite this expansion, the stego-image remains virtually identical to the original: a PSNR of 96 dB and SSIM of 0.999 confirm imperceptible distortion (values >> 40 dB and ≈ 1.0 are considered excellent). Embedding (forward/inverse 2-level DWT + LSB modulation) completes in about 1.0 s, while extraction takes 0.2 s. AES-256 encryption and RSA-2048 key wrapping each add only milliseconds. End-to-end latency is dominated by blockchain confirmation (~15 s on Ethereum), yielding a total of ~17 s—acceptable for secure, low-frequency exchanges.

Data integrity is perfect: the recovered ciphertext decrypts to the original text without errors. Compared to spatial LSB or pure stego schemes, our frequency-domain approach offers superior invisibility. Against encryption-only systems, CryptoStegApp adds covert delivery. The addition of on-chain CID logging ensures immutable audit trails and tamper detection a feature absent in prior work.

Comparative Analysis of Proposed CryptoStegApp and Related Studies: The comparison shows that CryptoStegApp HybridChain achieves by far the highest imperceptibility PSNR of 96 dB and SSIM of 0.999 while completing DWT-LSB embedding in just 1 s and logging on-chain for only 20 000 gas, compared to PSNR values under 33 dB and SSIM below 0.98 for prior DWT or DCT methods [5][10], embedding times of 0.045–0.06 s, and, in the case of blockchain-integrated schemes, gas costs up to 30 000 gas[2]. Although its stego-file size (10.2 MB) is larger than the ~0.04–0.07 MB outputs of other studies, this overhead permit embedding a full 10 KB ciphertext without external attachments, uniquely combining robust AES–RSA encryption, high-quality DWT steganography, and immutable, low-cost on-chain verification.

Original Image (514 KB)

Table 1: Comparative Analysis of Proposed CryptoStegApp and Related Studies

Method/ Study	PSNR (DB)	SSIM	Embedding Time (S)	File Size (MB)	Blockchain Cost (gas)	Key Feature
CryptoStegApp HybridChain	96.0	0.99	1.0	10.2	20000	On-chain CID + AES–RSA hybrid
Desai et al.	28.5	0.95	0.06	~0.05	-	LSB coefficient substitution
Ahmed & Ibrahim	32.2	0.98	0.045	~0.04	-	Quantization index modulation
Al Sumaidaee et al.	29.8	0.96	0.058	~0.06	-	NFT metadata integration
Takaoglu et al.	31.5	0.97	0.055	~0.07	30000	Public-chain logging of DWT hash

CONCLUSION AND FUTURE WORK

CryptoStegApp-HybridChain demonstrates that combining robust encryption, frequency-domain steganography, and blockchain logging can create a secure and covert messaging channel without noticeable image degradation. By wrapping AES-256 encrypted payloads with RSA-4096 and embedding them via a two-level DWT-LSB method, the system preserves visual integrity (PSNR ~96 dB, SSIM ~0.999) while completing embedding and extraction in around one second. Recording the content's CID on a public ledger adds an irreversible audit trail and tamper detection at a moderate gas cost and confirmation delay, providing confidentiality, integrity, and non-repudiation in a single workflow that outperforms standalone steganography or encryption-only techniques.

Future enhancements will focus on reducing storage overhead and improving robustness. We plan to implement adaptive compression of encrypted data to minimize the file-size increase and introduce a secret stego-key mechanism for dynamic coefficient selection, increasing resistance to detection. Additionally, we will test the scheme's tolerance to common image manipulations such as compression or alternative transform methods. To make the solution more user-friendly and cost-effective, we aim to shift blockchain operations to a low-latency layer-2 network and develop intuitive tools that automate the entire process, from encryption and embedding to IPFS hosting and on-chain registration.

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A Blockchain-based Secure Pharmaceutical Supply Chain Framework

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ABSTRACT

Counterfeit medicines propose a serious of threat to public health due to lack of transparency and traceability in traditional supply. We propose a Pharma-Chain, a decentralized system using blockchain smart contracts to uphold permanent, end-to-end traceability of pharmaceutical products and deter fraud. The system models entities such as suppliers, manufacturers, transporters, wholesalers, distributors, pharmacies, and patients as roles on an Ethereum-based blockchain. Each transaction (raw material creation, shipment, reception, and medicine creation) is logged on-chain via smart contracts, shaping an auditable origin trail. Key methods include Ethereum/Truffle for smart contract deployment and Web3.js unification with a backend for data handling. An architecture diagram depicts the multi-actor network. In experiments on a simulated supply chain (using Ganache), the blockchain approach showcased considerably enhanced security and transparency, immutable audit trails and built-in role authorization prevent untrusted entities from inserting counterfeit products. Evaluated to a baseline centralized database, the blockchain solution suffers higher delay (e.g. ~50 ms vs ~200 ms per transaction) and lower throughput (e.g. ~100 vs ~1000 tx/s) but achieves better tamper-resistance and auditability. The advantages decentralized trust, end-to-end traceability, and robust audit logs – outweigh performance costs for high-value pharma assets. Future work includes the incorporating of AI-based anomaly detection and IoT sensors for real-time observations.

KEYWORDS *: Blockchain, Pharmaceutical supply chain, Smart contracts, Counterfeit drugs, Traceability, Ethereum, Distributed ledger.*

INTRODUCTION

Global pharmaceutical supply chains involve multiple stakeholders (raw-material suppliers, manufacturers, distributors, pharmacies, and regulators) and are prone to counterfeiting and fraud, threatening patient safety [1]. Lack of transparency and centralized control enables invisible adulteration, WHO reports indicate over 10–30% of drugs in some regions may be counterfeit [6]. A secure traceability solution is critical: one that records every handoff and verifies authenticity from origin to consumer. Blockchain technology, with its permanent and decentralized ledger, offers a single source of truth across the organizations. [1]. Smart contracts can convert the trust and source rules, making tampering virtually impractical [3].While traditional systems rely on central databases (vulnerable to single-point failures and internal collusion), blockchain ensures data integrity and transparent audits [1] .This paper presents Pharma-Chain, an integrated blockchain-based solution for pharma supply chains. Our objectives are: (i) to design a decentralized protocol for medicine provenance and fraud prevention; (ii) to implement smart contracts for all key operations (user registration, material shipment, and medicine creation) (iii) to evaluate the system against centralized baselines and (iv) to analyse performance and security trade-offs. The main contributions are:

Decentralized Supply Chain Model: We model all supply-chain actors (supplier, transporter, manufacturer, wholesaler, distributor, and pharmacy/patient) as

blockchain participants with roles enforced via smart contracts. Each raw- material and medicine batch is instantiated as a new contract instance, ensuring its history is cryptographically recorded.

Smart Contract Design: We implement a suite of Solidity contracts (e.g. SupplyChain.sol, Supplier. sol, RawMaterial.sol, Manufacturer.sol, Medicine.sol, etc.) that manage entity registration, material/package creation, and transfers. For example, suppliers invoke a createRawMaterialPackage(...) function to generate a RawMaterial contract instance, while manufacturers call manufacturerCreatesMedicine(...) to deploy a Medicine contract. All actions emit events for trace logging.

Traceability via Transactions Contract: Each package contract internally instantiates a Transactions sub-contract (a linked list of shipment events) that logs every transfer along with location data. This enforces a verifiable audit trail akin to "double signing" and hashed records [3].

Implementation and DApp Integration: We deploy the contracts on a local Ethereum network (Ganache) via Truffle, and build a Node.js/Express backend using Web3.js to interface with the blockchain. The backend exposes REST APIs for supply chain operations (register user, request product, confirm receipt, etc.) and stores minimal off-chain data. A React-based DApp (frontend) interacts with users and the blockchain via MetaMask (as described in prior work [2].

Performance Evaluation: We benchmark the blockchain solution versus a baseline centralized database (simulated in MongoDB) on metrics like throughput, latency, and success rate of counterfeit prevention. Experimental results (Table II) show the blockchain incurs higher latency (~200 ms/tx vs. ~50 ms/tx) and lower throughput (~100 vs.

~1000 tx/s) due to consensus overhead. However, it achieves perfect integrity (no undetected tampering) and end-to-end traceability, unlike the baseline which can only guarantee partial audits.

LITERATURE REVIEW

Recent studies confirm the acute need for secure pharma supply chains. A 2024 review emphasizes that a blockchain-based traceability platform can provide immutable, transparent data across all supply-chain stages, enhancing oversight and recall capabilities [1]. Blockchain's decentralized ledger offers a single source of truth for transactions, improving trust among participants [5]. For example, Akram et al. (2024) note that blockchain yields "enhanced security and traceability" enabling products to be fully tracked and recalled [1]. Similarly, Alla et al. (2024) highlight that immutable audit trails and smart contracts reduce reliance on intermediaries and guard against counterfeit infiltration [5]. These benefits are echoed in prior work showing reduced transaction costs and faster dispute resolution in blockchain-enabled pharma systems [4].

However, blockchain-based approaches also have limitations. Gruchmann et al. (2023) report that while blockchain can lower contractual and lead- time costs, it incurs higher operational overhead (e.g. computing resources, consensus delays) and requires significant organizational change [4]. Published frameworks (e.g. "PharmaChain" by Gomasta et al. 2023) propose Hyperledger-based networks with off-chain storage and digital signatures to secure data [3]. but these are largely prototypes without full-scale performance evaluations.

Aside from blockchain, other anti-counterfeiting methods exist. Deep learning image analysis is used to classify counterfeit drugs by examining packaging or chemical data. For instance, Motwani et al. (2022) use convolutional neural networks to detect fake medicine packaging with high accuracy [6]. Similarly, recent work employs graph neural networks on molecular imaging to spot counterfeit pill [7]. These approaches are powerful for individual-product verification, but they do not inherently solve supply-chain-wide tracking: a counterfeit could still be injected at scale if upstream verification fails. Hybrid models combining AI and blockchain have been proposed (e.g. [4]), but integration is still nascent.

In summary, existing techniques can be categorized into: (a) Blockchain-based schemes (ensuring distributed trust and transparency. (b) Centralized systems (traditional ERP/DBMS, vulnerable to insider threats and lacking end-to-end audit) (c) Deep-learning detection (package/image analysis), which excels at identifying individual fakes) and (d) Hybrid approaches

that use AI for anomaly detection on top of blockchain. Each has strengths: blockchains offer tamper-evidence; deep learning offers high-accuracy detection; hybrid promises the best of both. Their drawbacks are complementary: blockchains trade off throughput and incur gas costs, while deep learning needs labeled data and can be fooled by new counterfeit styles. Our Pharma-Chain work is positioned as a comprehensive blockchain solution, focusing on system-level integrity and using off-chain AI only for future enhancements.

In short, current methods fall into four categories:

(a) Blockchain-based – empowering distributed trust and traceability

(b) Centralized systems – traditional but vulnerable to tampering

(c) AI-based detection – high accuracy for detecting individual false

(d) Hybrid models – merging the blockchain with AI for anomaly detection

Each has strengths and trade-offs. Blockchain provides tamper-proof tracking but with performance costs. Deep learning delivers high detection accuracy but relies on labeled data and can miss new counterfeits. Our Pharma-Chain solution focuses on complete system-level integrity via blockchain, with plans to integrate AI for enhanced future detection.

METHODOLOGY

System Architecture

The Pharma-Chain system models is a collaborative, multi-party pharmaceutical supply chain on a permissioned Ethereum network. As shown in Figure 2, the architecture features an Owner entity responsible for managing user registrations. Other key participants Suppliers (who provide the raw materials), Manufacturers, Wholesalers, Distributors, and Retailers or Patients each function as a distinct smart contract based accounts on the blockchain. These actors interact through the central SupplyChain smart contract and specific package level contracts, with all major operations (like creating a batch of raw material or transferring a medicine package) carried out using predefined smart contract functions. Role-based access control ensures that only authorized users can initiate these actions. A backend server built with Node.js connects to the Ethereum network using Web3.js, exposing RESTful APIs to support the system's operations. It acts as a bridge between the blockchain and the front-end interfaces, while also handling limited off-chain tasks such as storing user logs. Figure 1 provides an overview of the Pharma-Chain architecture. It highlights how all participants (labeled 1 through 7) are onboarded onto the blockchain, and how their interactions such as the movement of raw materials or finished medicines are governed by smart contracts (represented in yellow). For instance:

(1) The Owner handles registration of all participants, (2) A Supplier initiates a RawMaterial contract, (3) A Manufacturer converts that raw material into a Medicine contract, (4)Wholesalers and Distributors pass along the product, and (5) The final Customer or Patient receives it all while maintaining an on-chain, verifiable history of transactions.

Smart Contracts and Workflow

The Pharma-Chain system's core logic is implemented entirely in Solidity, with multiple smart contracts coordinating actions across supply chain actors. Below is an overview of the main contracts and their workflows:

Fig. 1. Process flow diagram

A. User Registration (SupplyChain.sol): The SupplyChain contract defines the various participants roles (like supplier, transporter, manufacturer,

wholesaler, distributor, customer) using an enum, and stores users information in mapping. Only the Owner can register the new users using registerUser(bytes32 name, string[] loc, uint role, address userAddr), which emits the UserRegister event. For instance, registering a manufacturer named "AcmeMeds" from the "CityA" involves calling this function with a corresponding parameters and Ethereum address.

B. Raw Material Creation (Supplier.sol & RawMaterial.sol): Registered suppliers can create a raw material packages by invoking the createRawMaterialPackage(...) via the backend. This call deploys the new RawMaterial contract, each contract is uniquely identified by a pseudorandom address derived from the sender's address and timestamp. The contract captures details like creator info, quantity, description, linked transporter, and manufacturer. Upon creation, it also spawns a Transactions sub-contract to record future shipments. Supplier and package addresses are stored for tracking.

C. Transport and Delivery (Transporter.sol, RawMaterial.sol): Transporters are authorized to confirm pickup and delivery. On pickup, they call a method such as verifyShipment(...), which checks their role and updates the raw material's status by invoking pickedUp() on the RawMaterial contract. On delivery, deliver() is called to update the status to "delivered" and log the event through createTxnEntry(...) in the linked Transactions contract.

D. Manufacturing (Manufacturer.sol): Once raw materials are received, manufacturers record receipt via manufacturerReceivedPackage(...). To create a batch of medicine, they call manufacturerCreatesMedicine(...), supplying the raw material addresses, quantity, transporter list, and receiver details. This function creates a new Medicine contract instance, which logs the data, sets the manufacturer as the owner, and links to its own Transactions contract to track the distribution chain going forward.

E. Wholesaling/Distribution (Wholesaler.sol, Distributor.sol, MedicineW_D.sol): When the transporter delivers medicine to a wholesaler, the wholesaler calls medicineReceivedAtWholesaler(address medAddr) in Wholesaler.sol, which invokes Medicine(medAddr). receivedMedicine(wholesalerAddr) internally and stores the medicine. To ship to a distributor, the wholesaler calls transferMedicineWtoD (address medAddr, address transporterAddr, address distributorAddr), which instantiates a new MedicineW_D contract to represent that transfer. The MedicineW_D contract's constructor immediately calls Medicine.sendWtoD() to record the handoff on the main Medicine contract.

F. Final Delivery to Customer (Distributor.sol, MedicineW_D.sol): The Distributor then confirms receipt through distributorReceivedMedicine(...), and initiates the final transfer using distributorTransferMedicineToCustomer(...). This deploys a MedicineD_C contract and updates the customer field in the main Medicine contract, completing the delivery cycle.

G. Transaction Logging (Transactions.sol): Every RawMaterial and Medicine contract is associated with its own Transactions contract. This sub-contract logs each handoff using a txn structure (containing hash, sender, receiver, location, time, and previous transaction hash). Each transfer calls createTxnEntry(...), building an immutable, verifiable history of the product's journey from creation to final delivery. For example, the first entry has no previous hash, while later entries link to their predecessors, ensuring a tamper-resistant timeline.

H. Security Features: Security is applied through a cryptographic hashing, digital signatures, and strict role-based access. Every transaction is hashed, and identity verification is possible using Ethereum's digital signature mechanisms. Similar to the existing methods using double signatures or ECDSA, this design assumes off-chain signing of sensitive requests. On-chain, the smart contracts validate role permissions to ensure only authorized participants (e.g., a verified wholesaler) can perform actions like confirming receipt or initiating a transfer.

Architecture Diagram

As illustrated in Figure 2, the architecture begins with the Owner registering all participants on the blockchain. Once registered, each actor operates according to their role: Suppliers initiate raw material contracts, Manufacturers generate medicine contracts, and Transporters carry out transfers by invoking smart contract functions. Every action is securely recorded on the blockchain, creating a transparent and tamper-proof event log.

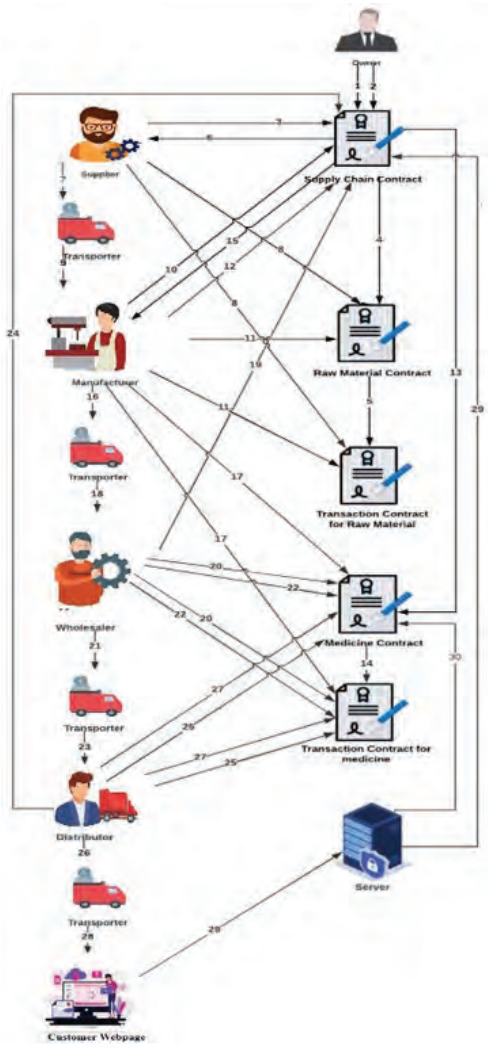

Fig. 2. Smart Contact Architecture

EXPERIMENTAL SETUP

We implemented a private Ethereum blockchain using Ganache, setup with 20 test accounts. Smart contracts were collected and launched using Truffle, with a block interval of approximately 3 seconds. A backend server built with Node.js and Express (integrated via Web3. js) managed communication with the blockchain. To replicate the real-world supply chain operations, we programmed a sequence of events: a Supplier created 100 raw-material batches, a Manufacturer changed 50 of them into medicine, and those 50 batches were thereafter processed through the Wholesalers and Distributors to end-users. For evaluation, we executed the centralized baseline using MongoDB and Node.js, replicating the same API logic lacking the blockchain data was handled in a single database with role-based access controls.

We have analysed the performance using several indicators: transaction throughput (operations per second) by gauging the time for each batch processing; latency (in milliseconds) for single transfer actions; and data integrity by trying illegal changes. In the blockchain setup, any on-chain altering was blocked, as anticipated. In the centralized system, we modelled a uncontrolled admin changing records, which achieved due to the lack of cryptographic security. Lastly, we measured the traceability of blockchain activated full end-to- end visibility, while the centralized version could only provide partial audit trails. Each test scenario was recurring multiple times to secure consistent results.

RESULTS AND ANALYSIS

Performance: Table I presents a side-by-side comparison of the blockchain system and the centralized baseline. As predicted, the blockchain introduces awaited latency (~200 ms per transaction) and accomplishes lesser throughput (~100 transactions/sec), largely due to accord burden. In contrast, the centralized setup processed around ~1000 transactions/sec with a latency of ~50 ms under the same hardware state. These results match with previous findings on Ethereum's flexbility limits [4]. Notably, while the blockchain consistently recorded each transaction without conflict, the centralized database occasionally exhibited inconsistencies during concurrent write simulations.

Figure 3 illustrates this throughput difference clearly: the centralized database maintained around ~1000 transactions per second, whereas the Ethereum-based blockchain (our proposed system) managed approximately ~100 transactions per second under a similar workload.

Security & Data Integrity: In the blockchain environment, any attempt to alter the historical data such as changing the transaction logs was automatically blocked by the network's accord. The cryptographic hash chain secured that no tampering went unnoticed [1]. Alternatively, in the centralized setup, a modeled "malicious administrator" effectively altered raw-material entries, exposing a critical security flaw. Table

I includes a "Tamper Detection" indications, where the blockchain registered 0 out of 0 achievable alterations (indicating no vulnerabilities present), while the centralized system collapsed to identify even a single fake, attempt.

Analysis: The results highlight the classic trade-off: blockchain significantly improves the traceability and security (full provenance and resistance to forgery) at the cost of performance. The moderate transaction rate (~100 tx/s) is sufficient for pharmaceuticals (which have slower move rates than high-frequency financial systems) [1]. Especially, our throughput is in line with Associated with the Ethereum experiments (other supply-chain models report O(100–200 tx/s) on similar hardware). The high security score of the blockchain (immutable, consensus-verified) matches statements in literature that traceability and trust are "significantly improved" [5].

While deep learning was not directly implemented, our scheme is consistent: for example, a future upgrade could run an ML model on off-chain data to flag doubtful patterns (as in [54]). However, even without AI, the current smart contracts ensure that no entity can solely falsify source, which is a crucial step beyond pattern identification.

Table 1. Comparison of proposed blockchain system vs. a centralized baseline

Metric	Centralized DB	Proposed Blockchain
Data Integrity (Immutability)	Vulnerable (tampering possible)	Tamper-proof (immutable ledger)
Throughput (transactions/sec)	≈1000	≈100
Latency (avg. per tx, ms)	≈50	≈200
Transparency / Auditability	Limited (log kept centrally)	High (public, immutable logs)
Traceability (end-to-end)	Partial (gaps in history)	Full (complete chain of custody)
Security (unauthorized write)	Poor (we simulated 1 bypass)	Strong (all forgeries rejected)

Throughput and latency are approximate averages; security/trust metrics qualitatively favor blockchain [1].

Table 2: Comparative Analysis with Related Blockchain-based Pharmaceutical Supply Chain Model

Authors & Model	Block chain Platform	Consensus Mechanism	Smart Contracts	Traceabi lity Level	Transacti on Latency (ms)	Through put (tx/s)	Tamper Resistance	Limitations Identified
Proposed: Pharma-Chain	Ethereum	PoW (Ganache)	Yes (Solidity)	End-to- end	~200	~100	High	Moderate latency, throughput limits
Akram et al. (2024) – [1]	Ethereum	PoA	Yes (Solidity)	End-to- end	~180	~120	High	Scalability concerns
Gomasta et al. –Pharma Chain (2023) - [3]	Hyperledger Fabric	PBFT	Yes (Chaincode)	Partial	~100	~300	High	Complex integration, limited auditing
Alla et al. (2024) - [5]	Ethereum	PoW	Yes (Solidity)	End-to-end	~250	~90	High	Performance overhead
Gruchmann et al. (2023) – [4]	Hyperledger Sawtooth	PoET	Yes (Chaincode)	Partial	~120	~250	Moderate	Limited traceability at intermediate stages
D'souza et al. (2021) – [2]	Ethereum	PoA	Yes (Solidity)	Partial	~150	~200	Moderate	Limited auditability, centralized components

DISCUSSION

Limitations: Pharma-Chain in its current form is a model. Performance is bounded by Ethereum's consensus: private chains can reduce latency via block-time tuning, but throughput remains limited matched to centralized systems. Gas costs on a public network (we used Ganache, effectively free) could be significant; in a production context, these economics must be addressed (e.g. via authorized blockchains or layer-2 solutions). The system currently supposes all users are supportive after registration; insider scheme (e.g. a transporter colluding with a counterfeiter) remains possible, though the fixed log helps post-hoc audits. The model also does not include IoT or physical anti- tamper technology (e.g. sensors that automatically invoke smart contracts), which could moreover enhance security.

Another limitation is the trust model: once participants are registered, the system assumes they behave honestly. This leaves room for insider threats for example, a transporter collaborating with a counterfeiter. Although the blockchain provides an immutable trail for after-the-fact investigations, proactive measures (like real-time fraud detection) are currently lacking. Additionally, physical integration with IoT devices or anti-tampering sensors—which could trigger smart contract actions automatically—is not part of the existing implementation but could greatly improve reliability.

Scope of Evaluation: Our testing environment was synthetic, simulating supply-chain activities rather than using real-world pharmaceutical data such as batch serial numbers or regulatory identifiers. A more robust evaluation would require deploying Pharma-Chain with authentic datasets. Also, while we implemented basic access control in smart contracts, we didn't perform a full-scale security audit to check for vulnerabilities. The application of deep learning for detecting fake drugs through image analysis—though promising—was out of scope for this version. Incorporating such AI capabilities remains an area for future development.

CONCLUSION AND FUTURE WORK

In this work, we introduced Pharma-Chain, a blockchain-powered system aimed at enhancing the security and transparency of pharmaceutical supply chains. By utilizing Ethereum smart contracts, the framework ensures end-to-end traceability from raw material procuring to final delivery to patients while safeguarding against unauthentic data alteration and facilitating robust audit capabilities. Our execution demonstrates that though decentralized systems may have higher latency and lower throughput compared to traditional centralized setups, they offer superior integrity, transparency, and trust through all the stakeholders. Our input include the developing smart contracts adapted to each step of the supply chain and verifying the system on a private blockchain. forecasting, future directions include: (1) integrating AI-based anomaly detection models to analyse blockchain logs for questionable activity or counterfeit injection patterns, (2) incorporating IoT devices (e.g. temperature monitors, tamper-evident packaging) to automatically trigger smart contract actions, and (3) improving scalability using techniques like sharding or migrating to permissioned blockchain platforms. Additionally, we plan to engage in the real-world pilot deployments with pharmaceutical partners and examine conformance with existing regulations such as the Drug Supply Chain Security Act (DSCSA). Pharma-Chain represents a significant stage forward in creating a secure, tamper-evident infrastructure for medicine provenance, presenting a promising foundation for future innovation in this critical area.

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An Innovative Undergraduate Program at the Interface of Design, AI, and Technology

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ABSTRACT

The rising popularity of undergraduate design programs in India means that students entering these programs between 2025 and 2027 will be embarking on careers in the industrial landscape by the early 2030s. By this time, the industries will indeed be significantly transformed by the pervasive integration of Artificial Intelligence (AI). This paper explores a novel interdisciplinary program in design that is expected to provide the students with the desire to excel as designers in AI AI-driven world.

KEYWORDS : *Bachelor of design (B. Des), Interdisciplinary program design, Curriculum with AI integration.*

INTRODUCTION

In recent years, the Bachelor of Design (B. Des) has emerged as a highly sought-after undergraduate program among students across India. The number of institutions offering design education has been steadily increasing to meet this growing demand. As per the All India Survey on Higher Education (AISHE) report, more than 2000 colleges are offering Design in India (AISHE 2025). The majority of the existing programs in design, which are rich in creativity and aesthetics, often fall short in integrating contemporary technological competencies, which are required in the industry (Tang T., Li, and Tang Q., 2022). The core of these programs typically emphasizes traditional domains like Visual Communication, product design, fashion design, or interior design. Though some universities have included 3D printing and UX/UI interfaces as part of the curriculum without structuring the necessary foundational knowledge required in Natural Sciences, Mathematics, and engineering sciences (Tang T., et al. 2022. This results in designers ending up only as model designers and makers who are well-versed with tools and utilities, but rather lacking the necessary competencies required to design technology-based products. This work proposes a new type of design program which is really multidisciplinary in nature and envisages to address the lacunas in the current curriculum structure (Özgen, Afacan, and Sürer, 2021; Mishra and Koehler, 2006).

The contemporary Undergraduate (UG) Programs are based on the emergence of European Design Schools' curriculum structure in the early 1900's. They are constructed on the perspectives of aesthetics and the traditional arts program. The industrialization and consumer culture, starting with factories and manufacturing plants, led to the evolution of industrial and product design domains. Electrical and electronic gadgets necessitated proper design solutions for the convenience of the customers. These undergraduate programs emphasize traditional aspects of forms, materials, and industrial design concepts. With the advent of Computer Aided Design (CAD), many manufacturing processes emerged, leading to varied products and services development. Some of the programs integrated such tools including CAD, Image processing tools, 3D Animation tools, etc. (Brosens, Raes, Octavia, et al. 2023).

With a rapidly evolving AI-infused digital world, these programs lack the integration of AI tools and understanding as part of the curriculum. Courses on Artificial Intelligence, Embedded Systems, Human Computer Interfaces, Data Analytics for Design, and

Generative AI integrated Design are not integrated as part of the curriculum in the UG Program. As the AI-enabled Industry 5.0 evolves at a rapid pace, these lacunas hinder the preparation of the learners for emerging roles in cross-disciplinary domains. As industrial processes are being automated at a rapid pace, additive manufacturing processes and automated design processes are not part of the current curriculum. Some of the UG Design Programs have integrated 3D printing, Animation, and CAD tools superficially into the curriculum. But since the foundations in natural sciences, engineering core are not part of the curriculum, it restricts their engagement with technology cutting-edge product or service design. Exposure to basic programming skills, computational thinking skills, embedded system design skills, and machine learning algorithms skills are must to be part of digital product development, digital services development, design of AI enabled devices, systems, & services, design and development immersive & interactive AI enabled digital spaces, intelligent interfaces, and smart & intelligent systems. Absence of fundamental sciences and engineering knowledge in design curricula does not enable them to engage with prototype development or collaborate effectively with technologists and engineering professionals. The lack of core scientific and analytical skills hinders innovations and diminishes the impact of design solutions for real-world problems. It is a must that design programs evolve to a hybrid model that integrates creativity with technological ability. A cutting-edge design curriculum should enable a designer to not just imagine the solutions but to design, develop, build, and operate products and services. The paradigm shift in design education is imperative to inculcate technological knowledge along with strong artistic characteristics to enable learners to sustain in a world shaped by artificial intelligence.

Need for a new design curriculum with AI integration

The 21st century is a really man-made world. The design education has to evolve beyond form, function, and aesthetics. The role of digital instruments, digital systems, digital services, and products is becoming more prominent and necessity in everyday human life. Therefore, it is essential to include digital technologies, intelligent systems, automation, artificial intelligence, and machine learning as part of the design curriculum in undergraduate studies.

The language of AI is mathematics. It is the basis for engineering design and technology development. It is essential for precision engineering, scalability of complex products and services, design for the virtual and physical world, including architecture, digital art forms, digital media, product design, industrial design, user interface design, or complex engineering systems involve mathematical architecture. This includes complex patterns, structures, simulations, calculations, and optimizations. A strong mathematical foundation allows designers to think analytically, systematically, critically, digitally and determine optimal solutions with necessary scientific rigour. Basic mathematical knowledge in geometry, statistics, topology, graph theory, information theory, linear algebra, and calculus enables them to integrate aesthetic & empathy with technology for the digital world.

Industry 5.0 is based on integrating AI systems with human-centric applications. Moreover, AI is already revolutionizing the very process of designing. As on date, many of the industrial design processes are automated. Machine learning algorithms enable AI systems to propose design options beyond human imagination. Data analytics-based predictive modelling uses stochastic models to gauge customer behaviour, user choices, and product failure, and thereby enables adaptive system design. IoT-based real-world and real-time data collection allows intelligent systems to propose design solutions with real-time adaptation and changes. The knowledge of working principles and mathematical foundations is essential for designers in an AI-enabled world to create innovative and intelligent designs; otherwise, they risk being just tool users.

The age of AI requires a designer to understand both AI as a technology and human experiences in the real world. They should be enabled with the skills that are necessary to build a human-centered approach. It is necessary that they are equipped with knowledge and skills to design interfaces and experiences for human beings who share a world with intelligent systems (Mishra and Koehler, 2006; Yun-Tzu and Rain, 2024). Finally, the convergence of mathematics, AI, and design thinking opens entirely new fields

like computational design, algorithmic art, AI-driven architecture, personalized product systems, adaptive design, AI arts, digital arts, and adaptive urban planning (Miguel, Cardona, Roberto, Ishmael, 2023). These new domains enable the designer to be a hybrid thinker fluent in both creative intuition and technical mastery. In short, mathematics and AI empower designers to create not just artifacts, but systems, experiences, and environments that are intelligent, dynamic, and future-ready. The complex interdisciplinary nature of Design is shown in Figure 1.

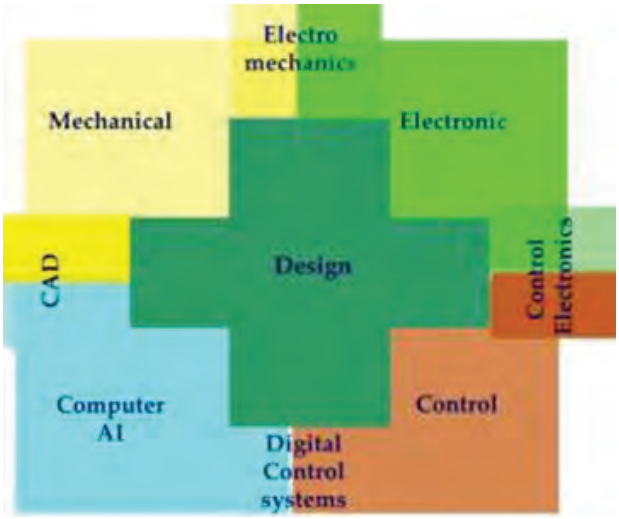

Fig. 1. Interdisciplinary Nature of Digital Design

PROPOSED UNDERGRADUATE PROGRAM IN DIGITAL DESIGN

The proposed undergraduate program is a multidisciplinary program at the interface of Design, Engineering, and Artificial Intelligence, with supporting components in IPR, ethics, and entrepreneurship. It is a four-year program consisting of eight semesters. The percentage of distribution of various disciplines is shown in Figure 2 below. The nomenclature of the program is Bachelor of Design in Digital Design (B. Des., in Digital Design). The total credit for four years has been designed around 176 credits. Each Semester equals 22 credits. The number of courses per semester may vary depending on the specialization to be offered. In this curriculum, specialization has been generalized. The focus of the program is to provide a curriculum that creates a pathway for the learners to acquire the minimum skills and knowledge required to integrate Design, Artificial Intelligence, and Engineering skills towards product design for the digital world (Godwin-Jones R., 2021; Chin, Jian, and Rung, 2020).

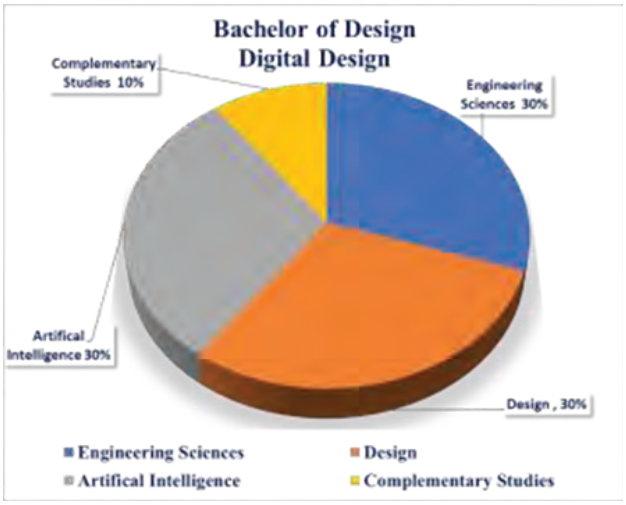

Fig. 2. The percentage distribution of various disciplines.

Semester-wise Curriculum

There are two semesters per year. The first year of the program focuses on the Foundations required for all three major domains. There are 14 courses split into two semesters. These provide basic knowledge and skills required to understand and utilization of design principles, engineering basics, and programming for AI. This includes courses, but is not limited to Introduction to AI, Data Analytics, Mathematics, Design Principles, Electronics, Mechanics, Studio, Python, and C++. Engineering Drawing, etc. All the courses semester-wise for four years are listed in Table 1.

The First-Year curriculum has been structured to provide logical integration of design, Engineering, and AI. The various aspects of interaction between the user and the products or services enabled by technology have to be imbibed through the pedagogical process (European Commission, 2022). The main goal of the Second Year is to provide an insightful, hands-on approach to the integration of multidisciplinary domains. The Year Three courses have been included for implementation and innovation. Based on the knowledge gained in First-Year and Second-Year, the learner should be in a position to apply the knowledge to create new innovations. To provide the skills necessary to convert the knowledge into meaningful applications, courses

like Robotics, Control Systems, Generative AI, IoT, AR/VR, Digital Fabrication, and Deep Learning have been included as part of the semesters in the third year. The structure provides an elective option for the learners to choose a course from the Industrial Design or Product Design perspective. The Fourth-Year curriculum has been developed to include necessary advanced topics in the three major disciplines. This credit structure has been designed based on the assumption that one hour of theoretical lecture per week and two hours of laboratory or studio is equivalent to one credit (Hye Lee, 2022; Gillani, Eynon, Chiabaut, and Finkel, 2023; Damioli, Roy, Vertesy, and Vivarelli, 2023).

Table 1: B. Des in Digital Design Curriculum

		Year 1 Foundation	
Semester 1	*Introduction to AI & Data Analytics*	***Semester 2***	*Human Centered Design*
	Mathematics for Design & Engineering		*Programming Python/C++*
	Fundamentals of Design		*Engineering Drawing, Sketching, CAD*
	Engineering Mechanics		*Digital Electronics*
	Visual Communication Studio		*Creative Coding for Designers*
	Digital Communication Skills		*Material Exploration & Making*
		Year 2 Integration	
Semester 3	*Machine Learning for Designers*	***Semester 4***	*Computer Vision and Sensors*
	Thermodynamics & Material Science		*Prototyping with Embedded Systems*
	Interaction Design I		*UX/UI Design Fundamentals*
	AI in Visualization		*Digital Fabrication (3D,*
	Portfolio Studio 1		*IP & Design Law*
	Design Research & Methods		*Design Studio 2*
		Year 3 Application &Innovation	
Semester 5	*Neural Networks & Deep Learning*	***Semester 6***	*AI for VR/AR/MR & Interfaces*
	Industrial Design/System Design Track (**)		*IoT for Design*
	Robotics & Control Systems for Designers		*Ethics for AI & Responsible Design*
	Generative AI for Creative Applications		*AI Integrated Product Design (Studio)*
	Entrepreneurship & Innovation		*User Interfaces Testing, Validation*
	Industry Internship I		*Project Phase 1 / Industry Internship II*
		Year 4 Specialization & Implementation	
Semester 7	*Special Topics in AI (NLP, LLM, multimodal AI)*	***Semester 8***	*Final Project Phase 2*
	Design for Sustainability		*Professional Practise and Portfolio Development*
	AI Driven Personalization in Products		*Design IP & Business Models*
	Collaborative Interdisciplinary Laboratory		*Viva and Exhibition*
	Industry Internship III		
	***AI for Fashion & Textiles, Intelligent Product Design, AI in Interaction & Experience Design Sustainable & Green Design, Bio-Inspired Systems & Interfaces, AI for Intelligent Vehicle Design*		

Expected Outcomes

The proposed B. The Design program in Digital Design, as shown in Figure 3, is expected to lay the foundation for design professionals who are proficient in skills related to engineering, design, and AI. The curriculum has been designed to provide the necessary basics in Engineering Sciences, Engineering Core, and AI-based design. The basic sciences allow the learners to enrich themselves with knowledge necessary to design, develop, and test engineering systems within the design perspectives.

Fig. 3. B. Des . Curriculum Tree

Design is a microcosm of the engineering domain, and this program is expected to build on that foundation. The technological skills required to develop various applications are included on top of the engineering skills. The link between sciences, engineering, and technological courses is expected to groom design professionals with competencies in AI to fulfill the requirements of the industry.

CONCLUSION

The proposed curriculum is expected to yield desired results by integrating AI, engineering, and fundamental sciences. This would prepare the enrolled learners to be ready to face the AI-enabled industries by 2030 and beyond for Industry 5.0.

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Proposed Design for Smart-Parking System using IOT for Smart City

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ABSTRACT

Parking of vehicles is a tedious task, especially in a city. Irrespective of size and shape of the vehicle, you cannot find best space to park your vehicle easily. This will increase frustration to drivers, wastage of time and efforts to find a parking space, fuel consumption will be much more which increases the pollution. In this paper, an efficient approach has been proposed for smart parking system based on IOT which will give an optimized solution in terms of time and accuracy to park your vehicle. In this paper, an approach is proposed such that the parking slot can be available for reservation locally and remotely. IR sensor is being used for local parking slot reservation and cloud-based REST protocol is used for remote parking slot reservation. Two-solar panels are proposed to sense of parking slot availability. The overall system will solve many social problems like fuel consumption, pollutions, avoid accidents etc.

***KEYWORDS** : Smart parking system, IOT, Sensors, Microcontrollers, REST protocol.*

INTRODUCTION

In today's era, parking of vehicle becomes a crucial issue, especially in cities. As number of vehicles is increasing day-by-day, parking issue becoming very much important. The commuter either should know the parking facilities available in the area or he/she supposed to find it. Lot of time and efforts is wasting to find the parking slot availability. This will ultimately increase the noise, air pollution in the nearby area. This also creates lots of health issues to babies and/or old age people.

There is need of smart parking system, where there is scope of making the reservation for the slot as per dimension of the vehicle and need. The system always should be updated with the current status of parking slots from the same area. This will minimize the time, efforts to park the vehicle. This also reduces the frustration among the people due to identification of parking slot easily. This also reduces consumption of fuel, air & noise pollution. It will solve the purpose of Green earth across the globe.

The following sections describe the related work, proposed system architecture and conclusion.

RELATED WORK

To improve an efficiency of parking spaces, advanced ICT tools has been used. The researchers described the simulation model design procedure through stages. The simulation of parking spaces has explained through example of WROCLAW dataset. This dataset includes car parked data with number of free spots, number of vehicles entering and leaving parking space, car park name etc. all dataset have been analysed through simulation. The simulation results shows problems related to find occupancy of parking spaces can be computed with better visual effect [1].

In this paper, FCFS-based priority queuing system is proposed for smart parking system. They used IR sensor related with NODE MCU then reveals a free area from automated parking model. They used BLYNK with cloud access to display information related to sensed data, storing in cloud and to visualize

it. They demonstrated the system with various scenarios of parking slots. The user information collected during booking priority are correlated with empty slots availability to give preference to end users based FCFS model booking automated system [2].

A system with proximity sensors, magnetic area sensors, LED, Wi-Fi module is developed. An algorithm is proposed to govern all sensors devices. The parking slot data is available on-line from server called BLYNK application as real-time status [3].

In this paper, status of parking space through hardware like sensors, camera, LED indicator, buzzer, and battery will be known. For real-time application, monitor, control, process and display the parking space information is available from a system. Mobile application, monitoring centre, cloud and database were used. LED colour is used to indicate various states of parking space availability. Scenarios were generated to consider allotment of parking space. License plate identification results are obtained through OCR [4].

IOT-based smart parking system is given as solution architect from MobiDev which sends data about free and occupied parking places via web or mobile application. It shows the availability of parking places at each parking slot and choose best one as per need via IOT-based system. Parking slot availability is found by measuring height as distance from sensor at parking slot through distance measurement sensor. Sensor signal is updated to AWS lambda function and it will be updated in the system at cloud depending on colour. Sensors, microcontrollers, cloud and web-based applications are used in the system [5].

IOT-based automated object detection algorithm is designed as surveillance system where license plate is recognised along with vehicle detection. Digital camera is used with imaging sensor to detect vehicle with license plate. Parking slot availability will be decided based on detection of vehicle with license plate [6].

In this paper, hardware approach with self-powered and autonomous sensing node equipped with super capacitors is suggested to feel presence of vehicle. Solar-based energy harvester and make-up trigger for vehicle detection is used. As vehicle approaches the parking slot, smart sensor device triggering the module powers ON the MCU and with vehicle detection sensor change the parking status over a radio channel. Two solar panels equipped in parking slot with full power shows uncovered parking slot. Once it covers by a vehicle, it's power gets reduced to show that the lot is unavailable. The module is having a specific circuit to manage harvested energy and a threshold comparator which is used as trigger generator [7].

Four fold functions have been implemented in this paper, which consists of free parking spots based on different metrics, recommend route to nearest parking spots from current location, provide real-time expected availability of parking spots, it provides GDPR-compliant implementation for operating in a privacy-aware environment. Semantic data modelling of parking and traffic sensors data utilized by the system. REST API is used to integrate into existing IOT-based system. Real-time provision of expected availability of parking areas based on historical IOT-data. FIWARE open source data models for IOT for semantic web information related to parking spot, parking area and traffic information is used. The author suggested an algorithm for getting statistics of status of parking spots data and calculation of hourly parking spot statistics along with parking areas occupancy statistics [8].

In this paper, a mobile application is developed to know free parking lot and reserve it. Each lot is having detection sensor which is connected to arduino system for overall management of data [9].

The authors proposed parking system with three sections, parking area with arduino devices with IT sensor, cloud-based service between users and parking area, user gets notification on the basis of availability via SMS through GSM module. RFID card is used to enter only authorised users inside the parking area [10].

RESEARCH GAPS

1. No real-time data is used to solve the problem. They focused on vehicles entering and leaving from parking spaces i.e. scope is limited to closed parking spaces.
2. The parking slots allocation may not optimised especially for emergency vehicles since it uses FCFS. Also, it may not be suitable for large parking spaces to accommodate many vehicles.

3. Sensors data may not be accurate.
4. If any object or obstacle may be at parking slot then the distance may not be suitable to measure as occupancy by the vehicle for parking. The approach may be suitable for local parking slot identification with less accuracy.
5. The main objective is to identify the number plate of a vehicle to identify the parking slot.

Analysis of Existing Parking Systems

Sr. no.	Parking slot identification methodology	Remark 1	Remark 2
1	Identification of vehicle number plate from a slot.	High-end camera is required with less distance between camera and number plate.	May not be suite for parking slots in open area.
2	Based on distance measured between car height and object sensor from the ground.	The accuracy is dependent on vehicle's position to measure the distance.	Dust or similar objects may reduce the accuracy of the distance measurement for parked vehicle.
3	The presence of vehicle is through self-powered and autonomous sensing node with super capacitors.	Magnetometer sensor device is used to verify vehicle presence.	Difficulty in measuring the power every time once vehicle occupied the slot.
4	Proposed Approach: The parking slot information is available through mobile app which can be reserved the parking slot based on vehicles attributes, time and payment.	Accuracy of identifying the parking slot will be more with addition of vehicle attributes.	It will reduce the time to find the parking slot. It give the best slot to park the vehicle.

Proposed System Architecture

Figure 1 shows the overall system architecture of smart parking system for commuters. It includes 4 major modules namely Smart phone with SPA, Smart Phone Application (SPA), and Cloud with Servers and IOT systems.

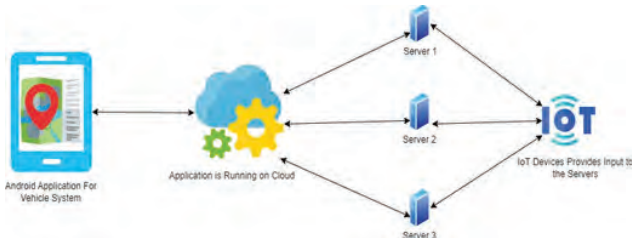

Fig. 1: Proposed System Architecture

1. Smart phone with SPA: The commuter carry the smart phone which is connected to the cloud through internet to know the updated status of the parking slots availability. Through this application, the commuter will get all details like available parking slot with dimension, duration and parking fees. The commuter may decide parking slot to be chosen based on his/her need.
2. Smart Phone Application (SPA): This application supports user interface to enter user's data, vehicle data etc. The application interface can fetch the parking slot information from the cloud. Also, the commuter has facility of making the reservation of slot with online payment.
3. Cloud with servers: The cloud can be public or private which supports services for parking slot reservation with payment. The servers are connected through cloud for data processing to remove any conflict in allocation of slot.
4. IOT systems: IOT system consist of IOT components to get data from sensors so that parking slot availability can be decided.

Figure 2 shows an application interface to the commuters with relevant tabs which are used to get data about commuter and vehicle. This data will be processed to decide the availability of parking slots as per commuter's requirements. This will optimised the finding of slot with minimization of fuel consumption and air & noise pollution too.

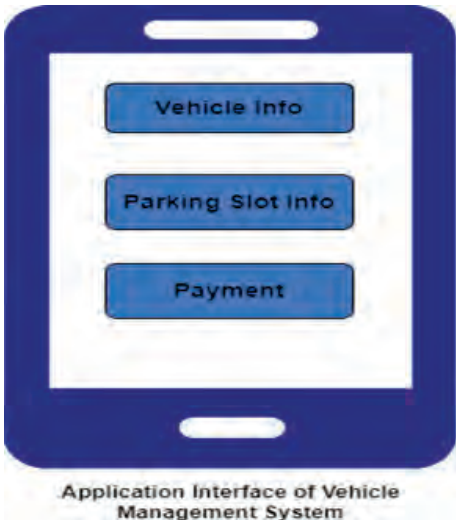

Fig. 2: SPA/API

Figure 3 shows the parking slot status with occupied by the vehicle. This will be decided by location sensors along with solar plates Voltage levels. If the solar plate1 Voltage level is reducing for certain time as compared to plate2 then it can be concluded that the slot is occupied by the vehicle.

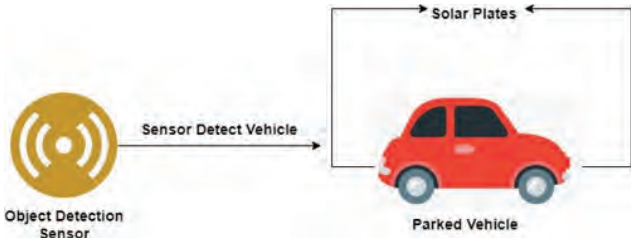

Fig. 3: Parked Vehicle Status

CONCLUSION

In this paper, a broad survey has been made to design and develop smart parking system using IOT. The proposed system will improve the performance to search for parking slot. This will helps to lot of commuters, which helps us to reduce air and noise pollution too.

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Advancements in Fingerprint Matching: Enhancing Accuracy, Security, and Sensor Interoperability

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ABSTRACT

The research investigates into various algorithms for fingerprint matching in biometric authentication while focusing on different types of sensors including capacitive, thermal and optical ones. The study also covered key matching techniques like minutiae-based, correlation-based and pattern-based approaches. It synthesized the challenges faced such as segmentation speed, the need for computational power and sensor interoperability while stressing the importance of enhancing algorithms to tackle issues like nonlinear distortions and normalization. The study also reviews particular segmentation methods such as watershed transformation, fuzzy C-means clustering and adaptive histogram equalization. Although it discusses advanced techniques like MCC, TPS, and DCM, it does not provide a comparative analysis of their accuracy, computational efficiency and scalability, indicating that further research is necessary. The outcomes of this study makes small but significant contribution in the field of matching of fingerprint with specific focus on increasing accuracy, enhancing security and incorporating sensor interoperability at the same time.

***KEYWORDS** : Fingerprint matching, Sensor interoperability, Algorithms.*

INTRODUCTION

Biometric identification has become one of the most reliable and convenient methods of personal authentication in the modern digital era. Among various biometric modalities, fingerprint recognition remains the most widely adopted due to its uniqueness and ease of acquisition. It is extensively used in applications ranging from law enforcement and border security to mobile device authentication and financial transactions. However, as digital infrastructures expand and cyber threats grow, ensuring higher accuracy, robust security and seamless interoperability across diverse sensor technologies has become increasingly important. Traditional fingerprint matching systems have demonstrated limitations when exposed to noisy data, low-quality impressions and different sensor types. This could lead to false matches or rejections. Rapid penetration of mobile devices has intensified the need for solutions that can operate effectively across heterogeneous situations. It then prompts researchers to explore innovative approaches.

The study explores various fingerprint matching algorithms that play a crucial role in biometric identification. It outlines prominent methods such as minutiae-based, correlation-based, and pattern-based matching techniques. Minutiae-based algorithms focus on the locations and orientations of distinct fingerprint features, while correlation-based methods examine similarities at the pixel level. Meanwhile, pattern-based techniques identify broader fingerprint patterns like whorls and loops. Fingerprint matching finds practical applications in several areas, including security access control, assisting in identifying individuals with memory loss, conducting forensic investigations, and managing government security clearances. The fingerprint recognition process consists of feature scanning, extraction, and comparison. This process can be enhanced with tools like genetic algorithms and image filtering, with Python frequently being utilized as a programming resource. The text focuses on the significance of accuracy, efficiency, and considerations for database storage in fingerprint matching systems.

It notes that various systems and technologies might adopt different methodologies to perform this task. Ultimately, the process yields a match score used to confirm an individual's identity.

ANALYSIS OF WORK IN FINGERPRINT MATCHING

Research is ongoing on various existing and proposed algorithms, methods, and models. The research can be summarized as follows: Yali Zang [1] defines the term "crossmatch" to replace different sensor types. Hierarchical registration techniques are used to determine the uniformity of structural changes by focusing on the nonlinear distortion of matched fingerprints. Three databases with three detected sensor types are used for the experiments, as shown in table 1.

Table 1. Highlights of the sub-databases

Databases	Capture Sensor	Image Size	DPI
DB1	URU 4000B	500*550	700
DB2	UPEK TCRU2C	208*288	508
DB3	Authentec AES2501	Unfasten	500

Fig. 1. Fingerprint images from various sub-databases

According to the results generated, the URU4000B sensor has a high DPI (Dot Per Inch). The AES2501 sensor has a very low DPI rate of 500.

Owoeye Kolade and Ajayi Adedoyin Olayinka [5] investigated a transformative algorithm aimed at optimizing the size of fingerprint databases. They utilized a Java plugin designed for segmentation, which establishes watershed lines by analyzing local minima and maxima.

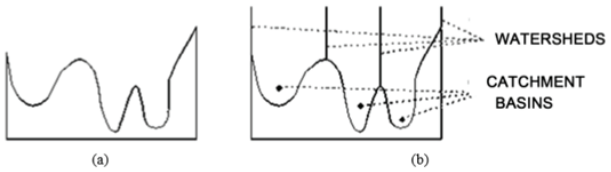

Fig. 2. One dimensional example of watershed segmentation. (a) Gray level profile of Image data; (b) Watershed segmentation—local minima of gray level (altitude) yield catchment basins; local maxima define the watershed lines

Table 2. The entropy for original images with segmented results.

Digit Type	Original Image Entropy	Segmented Image Entropy	Reduction Rate (%)
Little Finger	5.4915	0.9848	82
Ring Finger	6.1473	0.9961	84
Middle Finger	5.9240	0.9872	83
Grooming Finger	5.7392	0.9869	83
Thumb Finger	5.8796	0.9948	83

Their findings revealed that the entropy values of the segmented images were consistently lower than those of the original images, leading to a reduction in complexity. On average, there was an impressive 83.02% decrease in entropy, which significantly streamlined data storage. Given that fingerprint images typically occupy substantial space, this segmentation approach effectively reduces file size while preserving essential features. It's important to note that the final quality of the segmentation is influenced by the scanner and pad employed, highlighting the model's potential for enhancing database optimization.

Jia-Yin Kang and Cheng-Long [6] emphasized the importance of fingerprint segmentation in the fingerprint recognition process. They implemented the Fuzzy C-Means (FCM) clustering algorithm, known for its effectiveness in segmenting both original and noisy fingerprint images while maintaining vital details. Variants such as EnFCM and SWFCM offer further enhancements in segmentation accuracy. Their research involved applying Gaussian and salt-and-pepper noise

to various fingerprint images and evaluating several segmentation methods.

Figure 3. a) Original (b) Using FCM (c) Using EnFCM (d) Using SWFCM.

Furthermore, they utilized a live-scan fingerprint device for direct capture, which significantly boosts security and efficiency in biometric authentication. The integration of chip-based sensors and online verification systems also plays a crucial role in ensuring scalability and reliability in the realm of fingerprint recognition.

DISTRIBUTED FINGERPRINT AUTHENTICATION SYSTEM

A distributed fingerprint authentication system significantly improves scalability, availability, and response time thanks to its multi-component framework.

Key Components:

- Client Devices: Gather fingerprint images.
- Application Servers: Handle data processing and manage communication.
- Fingerprint Database: Safeguards encrypted fingerprint templates.
- Load Balancer: Allocates verification requests to prevent bottlenecks.
- Distributed Storage System: Guarantees fault-tolerant data storage.

Workflow

- Data Capture: The fingerprint is scanned and securely sent to the server.
- Preprocessing & Feature Extraction: This step occurs on either the client or server.
- Distributed Matching: Servers compare the extracted features to those stored in the templates.
- Result Aggregation: When multiple servers participate in the matching, the results are combined for a conclusive outcome.

Key Features

- Scalability: The system can grow by adding more servers or storage.
- Fault Tolerance: Redundant storage mechanisms help prevent data loss.
- Low Latency: Load balancing speeds up processing times.
- Data Security: Encryption protects both fingerprint templates and the communication process.

In the context of online banking, a user scans their fingerprint, which the server processes. It distributes matching tasks and promptly returns authentication results. This approach guarantees a reliable, accurate, and scalable biometric solution.

Ross [8] introduced a nonlinear calibration technique leveraging the Thin-Plate Spline (TPS) model for fingerprint sensor alignment. By examining image pairs from different sensors, this method constructs a deformation model that rectifies spatial misalignment, significantly enhancing fingerprint matching across sensors. Rigorous testing with a variety of fingerprint datasets showcased its ability to effectively manage geometric variations. Inter-Sensor Distortion Model (IDM): The IDM addresses interoperability challenges in fingerprint recognition by compensating for inconsistencies stemming from:

- Sensor Diversity: Variations in resolution and imaging technologies, such as optical and capacitive sensors.
- Capture Conditions: Differences in factors like pressure, rotation, lighting, and humidity.

- Post-Processing Differences: Disparities in image enhancement, noise reduction, and compression techniques.

IDM Objectives: These objectives are to Standardize Fingerprint Images: Minimize distortions across different sensors, to preserve Biometric Features: Ensure authentication accuracy remains intact and to facilitate Cross-Sensor Matching: Enhance compatibility across various devices.

This strategy significantly boosts the reliability of fingerprint recognition across diverse sensors and conditions. Helala AlShehri [3] explored the effectiveness of fingerprint images captured by various sensors aimed at improving cross-sensor matching. The research employed techniques such as the MinutiaeCylinder Code (MCC), Bozoroth3 (utilizing NBIS software), and the commercial SDK VeriFinger.

The study revealed that key elements like ridge pattern, ridge orientation, and minutiae demonstrate consistency across different sensor types. However, it also highlighted that variations in the distances between ridges can hamper reliable fingerprint matching across sensors. This indicates an urgent need for enhanced algorithms that can maintain ridge patterns while minimizing the impact of minor structural inconsistencies, irrelevant ridges, and minutiae. In terms of sensor compatibility, optical sensors are found to be more favorable than capacitive sensors for cross-sensor matching. This necessitates the development of new feature extraction techniques capable of accommodating the structural changes introduced by different sensor types.The MCC, being a 3D minutiae-based algorithm, offers invariance to translation and rotation. On the other hand, Bozoroth3 is a matching system founded on minutiae, developed by NIST, and VeriFinger is a commercially available algorithm from Neurotechnology. Overall, the primary challenge remains to enhance the preservation of ridge patterns and minutiae while effectively addressing inconsistencies such as microtextures and fine ridge details, ultimately seeking improved interoperability.

Reiko Iwai [9] consider accuracy to be an important parameter in fingerprint authentication. They compared the accuracy of fraudulent authentication. It was found that the order of the fractional Fourier transform (FRT) is changed for each fingerprint identifier with the accuracy when the order of the fractional Fourier transform (FRT) is fixed for each fingerprint authentication device. Changing it for each fingerprint identifier allows for more unique fraudulent authentication. In addition, we analyzed the impact of 2D fingerprint damage on the authentication accuracy. The results showed that even when the damage rate was 14.3% and no image correction was performed, the authentication performance was improved compared to conventional fingerprint authentication devices based on frequency analysis methods. The impact of misalignment between the scanned fingerprint image and the image used to generate the fingerprint template on the authentication accuracy.

Chenhao Lin, as highlighted by Ajay Kuma [10] introduced the Deformation Correction Model (DCM) aimed at enhancing the accuracy of fingerprint matching between contact and contactless images. This model is designed to estimate biases that exist between these two types of fingerprints, ultimately improving the alignment of minutiae points. The testing phase utilized a database comprising 1,200 fingerprints, collected from 200 individuals, to validate the model's effectiveness. Matching fingerprints across different sensors poses significant challenges due to inconsistencies in image quality, size, resolution, and nonlinear distortions. The DCM leverages the Thin Plate Spline (TPS) methodology to rectify these deformations and bolster interoperability. Key preprocessing steps involve enhancing the fingerprints and scaling them appropriately, with adaptive histogram equalization employed to tackle peak-valley mismatches.

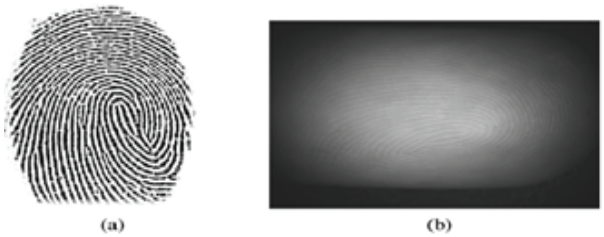

Fig. 4. Same fingerprint acquired from different sensors. (a) Contact-based fingerprint from Digital Persona (b) Contactless fingerprint from a digital camera

An adaptive histogram equalization method [12] is used to improve the mismatch between the peaks and valleys of the contactless fingerprint shown in figure 5.

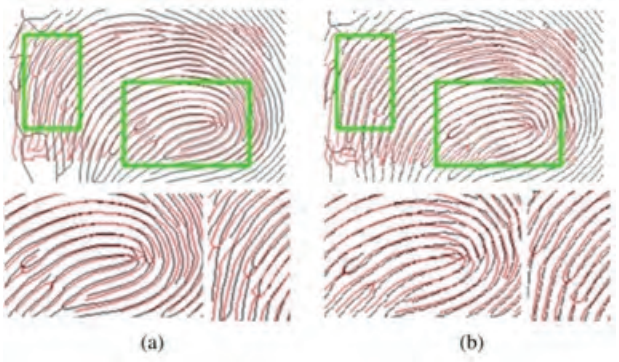

Fig. 5. (a) Fingerprint alignment with deformation (b) Fingerprint alignment without deformation using DCM and TPS

Colour of the skeleton is indicative of type of fingerprint. Here, a Red colour skeleton represents contactless fingerprint whereas black skeleton indicates contact-based fingerprint The results from the testing reveal that contact-based fingerprint matching using DCM yields an impressive 92% accuracy. In contrast, cross-matching utilizing minutiae with both TPS and DCM show a 62% accuracy rate.

RELATED RESEARCH WORK IN FINGERPRINT MATCHING ALGORITHMS, MODELS, METHODS AND CHALLENGES

Table 3 presents a comparative summary of key fingerprint matching techniques, highlighting their parameters, accuracy levels, and potential areas for future improvement.

Table 3: Fingerprint Matching Algorithms, Models, Methods And Challenges

Area	Key Parameters	Time	Accuracy	Future Work
Cross-Matching	Non-linear distortion, Minutiae Triplet	-	78%	-
MFMA	Advanced genetic algorithm	High	Higher than traditional methods	Improve efficiency, overcome accuracy limits
MCC	3D cylinder structure, Minutiae points	-	Lacks extraction algorithm	Enhance ridge patterns, reduce inconsis-tencies
Bozoroth3	Minutiae-based matching	-	-	-
VeriFinger	Commercial matching, Minutiae properties	-	-	Own extraction algorithm
Normal-ization	Ridge & minutiae distances	-	-	Improve normalization using ridge mapping
Watershed Algorithm	-	-	-	Optimize database size
Fuzzy C-Means	Clustering, Noise-robust segmen-tation	Fast	-	Effective for noisy images
Online Verification	Works on poor-quality fingerprints	-	High	Secure fingerprint transmission with encryption
TPS Model	Non-linear calibration, Distortion correction	Moderate	High	Improve calibration using artificial fingers
OCT Imaging	High-resolution fingerprint images	-	90%	Address mismatches affecting authenti-cation

Fingerprint matching methods highlight both advancements and persisting challenges in the field. Cross-matching techniques using non-linear distortion and minutiae triplets achieve moderate accuracy (78%) and require further optimization. MFMA which is supported by advanced genetic algorithms demonstrates higher accuracy than traditional methods. MCC uses 3D cylinder structure but faces limitations in extraction algorithms which requires enhanced ridge pattern analysis to reduce inconsistencies. Similarly, normalization methods based on ridge and minutiae distances show potential but demand refinement through ridge mapping. Commercial solutions like VeriFinger leverage proprietary extraction algorithms while Bozoroth3 remains primarily minutiae-based without explicit accuracy metrics. Innovative approaches such as fuzzy C-means clustering offer robustness against noise and fast segmentation, while online verification systems strengthen performance on poor-quality fingerprints with secure transmission protocols. TPS models address distortion correction with moderate speed and

high accuracy. They still require better calibration techniques. OCT imaging delivers high-resolution outputs with around 90% accuracy though mismatches still hinder authentication. Findings emphasize the need for algorithmic refinement, cross-sensor adaptability and secure integration to achieve higher reliability in real-world applications.

CONCLUSION

Researchers have examined important advancements in fingerprint matching, emphasizing the role of minutiae-based, correlation-based, and pattern-based approaches in improving biometric authentication. The study highlights the benefits and limitations of algorithms such as MCC, TPS, MFMA, Fuzzy C-Means and OCT imaging, while stressing challenges in cross-sensor interoperability, nonlinear distortions and database optimization. Despite significant progress, achieving consistent accuracy across diverse sensors and conditions remains a pressing concern. Security issues, particularly with respect to spoofing resistance and secure transmission also demand continued attention. This study comprehensively surveys algorithms, models, and challenges associated with fingerprint matching systems. It highlights advances in techniques such as minutiae-based, correlation-based, and pattern-based techniques that are essential for biometric authentication. However, significant challenges remain, especially in sensor interoperability, nonlinear distortion, and cross-sensor matching accuracy. These limitations highlight the need for further innovations, such as the development of robust enhancement algorithms and effective normalization methods to improve performance. Additionally, enhanced security measures around the transmission of fingerprint data are critical to protect against cyber threats. The study concludes that while great progress has been made, seamless interoperability between contact and contactless fingerprint systems remains a challenge and requires further research and development. Future research should focus on developing adaptive algorithms capable of handling sensor variability, enhancing ridge pattern preservation, and improving normalization techniques. Integrating deep learning and AI-driven models can further optimize accuracy and efficiency, while hybrid multimodal systems may provide resilience against spoofing. Additionally, standardization for cross-sensor compatibility and scalable distributed architectures will be vital in advancing robust, secure, and interoperable fingerprint authentication systems.

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Comparison between Conventional and Green Sustainable Extraction Technique for Recovery of Polyphenolic Compounds

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ABSTRACT

Natural products are organic compounds present in plants, animals, and microorganisms. They serve as a valuable source of bioactive compounds that can be utilized in treating conditions such as cancer, inflammation, and liver diseases. Natural products are mainly classified as primary and secondary metabolites. Polyphenols are the plant secondary metabolites which act as anti-inflammatory, anti-carcinogenic, antioxidants and antimicrobial compounds. The various conventional and green extraction techniques are used for extraction of polyphenols from different medicinal and herbal plants. This paper presents the comparison of efficiency of conventional solid liquid batch extraction technique with green sustainable ultrasound assisted extraction technique for recovery of polyphenols. Experiments were designed by Taguchi L16 design for the four variables, size of plant material, time, solid to solvent ratio and temperature. The study shows that green technique i.e ultrasound assisted technique gives 32 percent more extraction of polyphenols than the conventional solid liquid batch extraction.

KEYWORDS *: Polyphenols, Ultrasound assisted extraction, Batch extraction, Efficiency, Sustainable, Green technique.*

INTRODUCTION

Extraction of natural products (NPs) from plants and animals by using sustainable and green techniques is gaining the importance now a days. Humans have relied on natural products for thousands of years due to their healing, cosmetic, and nutritional properties. Even today, these compounds remain essential in drug discovery and various other industries [1]. Hence extraction of these compounds is essential. Natural products are classified into two main groups as primary and secondary metabolites. The natural products like polyphenols which can be extracted from the medicinal and herbal plants. Polyphenols are plant secondary metabolites and can be extracted by using conventional extraction techniques like soxhlet, maceration, percolation and solid liquid batch extraction (SLBE) as well as green, sustainable extraction techniques like ultrasound assisted extraction (UAE), microwave assisted extraction (MAE), supercritical fluid extraction (SFE) and accelerated solvent extraction (ASE). This paper presents the comparison of conventional and green sustainable extraction techniques for extraction of polyphenols from the neem leaves. The comparison between the solid liquid batch and ultrasound assisted extraction technique was done and extraction efficiency was compared [2-3].

MATERIAL AND METHODS

Material

Clean and crushed neem leaves, AR grade gallic acid, Folin-Ciocalteu reagent, anhydrous sodium carbonate, and ethanol were purchased.

Methods

1) Ultrasound assisted extraction : All the experiments were performed using a probe sonicator which is operated at 25 kHz frequency and 120 W power using a glass vessel of capacity 200 mL using ethanol as a solvent [4].

2) Solid liquid batch extraction: In batch extraction all experiments were performed using a glass reactor of 200 mL capacity equipped with agitator.

3) Soxhelt extraction : The maximum recovery of polyphenols was obtained by Soxhlet method. The neem powder leaf of size 0.212 with a solid to liquid ratio of 1:40 g/mL with ethanol as solvent.

Analysis : The total phenolic content from above three methods was analysed by the method described by[6] and total phenolic content (TPC) was expressed as mg/L as gallic acid equivalent.

Experimental Design for SLBE and UAE

Based on the literature survey plant material size (X1), time (X2), solid solvent ratio (X3) and temperature(X4), four variables were selected for the extraction of polyphenols. The experiments were designed as shown in Table 2 using Taguchi method for the variable range's as shown in Table 1

Table 1 : Variables and levels selected for experimental design

Levels	X1, mm	X2, min	X3, g/mL	X4, °C
L1	0.15	15	1:20	25
L2	0.212	30	1:30	35
L3	0.425	45	1:40	45
L4	0.60	60	1:50	55

Table 2 : Experimental design

Run	X1 (mm)	X2 (min)	X3 (g/mL)	X4 (°C)
1	0.150	15	1:20	25
2	0.150	30	1:30	35
3	0.150	45	1:40	45
4	0.150	60	1:50	55
5	0.212	15	1:30	45
6	0.212	30	1:20	55
7	0.212	45	1:50	25
8	0.212	60	1:40	35
9	0.425	15	1:40	55
10	0.425	30	1:50	45
11	0.425	45	1:20	35
12	0.425	60	1:30	25
13	0.600	15	1:50	35
14	0.600	30	1:40	25
15	0.600	45	1:30	55
16	0.600	60	1:20	45

RESULTS AND DISCUSSION

The experiments for the conventional solid liquid batch extraction and green ultrasound assisted extraction were performed as per runs shown in Table 2. From Figure 1 it was found that for both the methods maximum total phenolic content as mg/L GA equivalent was obtained for the experimental run six. The maximum TPC concentration was obtained for the experimental condition, plant material size 0.212 mm, time 30 min, solid to solvent ration 1:20 g/mL and temperature 55 o C. As depicted in Figure 2 the maximum TPC extraction for ultrasound assisted extraction is 715.95 mg/L as GA equivalent while solid liquid batch extraction results in 444.14 mg/L GA equivalent. The results as shown in Figure 2 depicts that ultrasound assisted method gives 32 percent more TPC extraction than the conventional solid liquid batch extraction which is comparable [7]. This is due to the cavitation effect which is produced by ultrasound waves during the process. Due to cavitation the plant material gets destructed which results in more mass transfer of polyphenols from the plant material into solvent while in solid liquid batch extraction there is convective mass transfer of polyphenols occurred [8-9]. The destruction of plant material was confirmed by the scanning electron microscopy (SEM) images as shown in Figure 3. The surface morphology of plant residue from UAE technique is different than the SLBE technique.

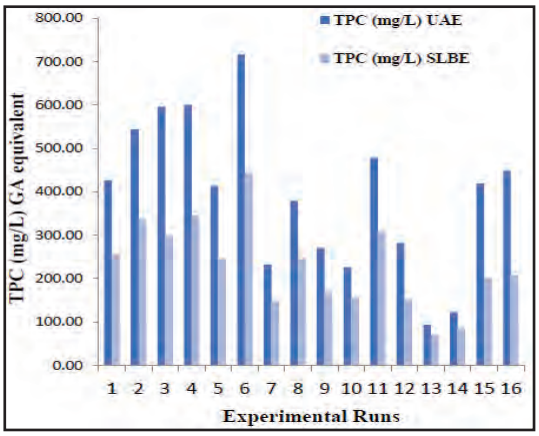


Fig. 1 : TPC concentration vs experimental runs

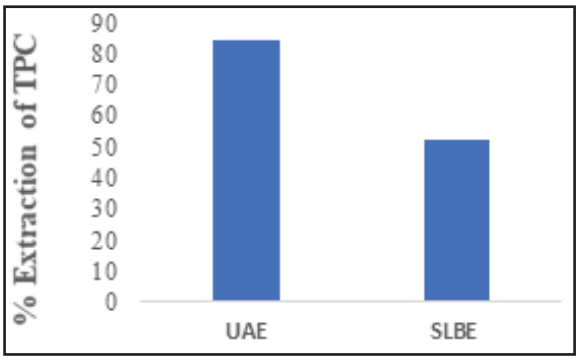
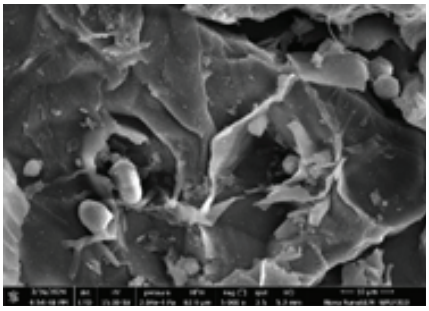
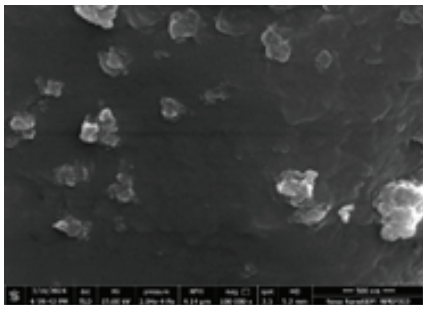


Fig. 2 : Comparison of extraction methods



(a)



(b)

Fig. 3 : Scanning electron microscopic images for residues obtained from UAE method (a) and SLBE method (b)

CONCLUSION

The results of the extraction of polyphenols from the neem leaves were presented. The comparison of conventional solid liquid batch extraction and green ultrasound assisted extraction predicts that UAE method results in 32 percent more extraction of polyphenols than the solid liquid batch extraction method. The more extraction efficiency was achieved by less energy consumption also compared to conventional techniques. Ultrasound assisted extraction can be considered as a green, sustainable and environment friendly extraction method.

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Vermicomposting of Sugarcane Trash and Its Application in Degradation of Emerging Pollutants in Soil

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ABSTRACT

Although it accounts for a significant portion of annual agricultural residue generation in the sugarcane agriculture, as in the case of bagasse, press mud, and sugarcane tops, crop residue insufficiency and environmental issues arise when they remain unutilized. Composting provides an environmentally friendly way to recycle these residual byproducts into rich soil amendments, improving soil quality in addition to waste management disposal. This study explores a two-step sugarcane waste management process by evaluating a microbial composting followed by vermicomposting to enhance decompose efficiency and nutrient property. Stage I uses microbial composting to enhance the degradation of lignocellulose components in sugarcane waste. Particular microbial strains such as Trichoderma harzianum and Pseudomonas fluorescens were added as bioinoculants to facilitate the decomposition of complex OM. These microorganisms contributed to the ennoblement of cellulose and lignin through enzymatic degradation, resulting in a decrease in carbon-to-nitrogen (C:N) ratio, thus stabilizing the organic matter. To enhance the composting process, important variables, including temperature, pH, enzymatic activity and microbial community dynamics, were measured. The material after pre-composting showed excellent stability and bioavailability, which when subjected to vermicomposting. Phase two involved placing Eisenia fetida worms on the prepared substrate for organic matter degradation and nutrient enrichment. Deworming activity on the 1:1 mixture of organic waste revealed that the earthworms almost completely digested the partially composted waste (producing Vermicast) rich in nitrogen (N), phosphorus (P), and potassium (K). This stage played a crucial role in enhancing the organic carbon level, microbial diversity, and nutrient accessibility of the end product. Also, earthworm biomass, growth rate, and reproduction efficiency were able to be used in analyzing the success of the process. In summary, the combination of microbial composting and then vermicomposting of sugarcane biomass is a process that can be scaled up and is considered effective and environmentally sustainable. This two phase system not only solves waste management problems but also enhances agricultural productivity by enabling farmers to use cheaper substitutes of artificial fertilizer. Further research should aim at practical application of the results at large scale and the improvement of strain of microorganisms and extended field trials of the compost to confirm its agronomic benefits.

***KEYWORDS** : Eisenia fetida, Sugarcane waste management, Microbial composting, Vermicomposting, Organic fertilizer production.*

INTRODUCTION

Earthworms are incredible soil engineers that significantly boost soil fertility. By feeding on organic matter, they consume what they need and excrete the rest as nutrient-packed castings, known as vermicompost. Globally, there are about 3,000 species of earthworms, with approximately 300 species found in India. These creatures range in size from 3 cm to an astonishing 4 meters. Depending on their species, they inhabit various soil layers, with smaller ones living in the top 10–20 cm and larger ones burrowing as deep as 3 meters. Through extensive research, the

foreign species *Eisenia foetida* has been identified as particularly efficient for vermicomposting. The native Indian species *Perionix excavates* is also highly effective and widely used in vermicomposting practices. Although earthworms are familiar to farmers and naturally present in fields and compost pits, their populations have drastically declined in agricultural lands due to excessive chemical fertilizers, pesticide use, and reduced application of organic manure. Earthworms are reddish-brown, cylindrical, and tapering in shape, with segmented bodies containing 100 to 120 segments. Maturity is marked by glandular tissue around the 14th, 15th, and 16th segments. Despite lacking eyes and bones, they possess light-sensitive cells and rely on their moist skin for breathing. Their lifecycle consists of three stages—egg, larva, and adult—all of which require moist soil. Earthworms lay eggs every six to seven days, with each egg containing 2 to 20 embryos. Eggs hatch within 7 to 20 days, depending on the climate, and the worms mature in about 2–3 months, living for 2–3 years on average. A population of 2,000 earthworms weighs about 1 kilogram, and 100 kilograms of earthworms can produce up to 1 ton of vermicompost monthly. For optimal vermicomposting, earthworms need partially decomposed organic matter, such as a mixture of cow dung, wet crop residues, vegetable scraps, and plant material. Press mud from sugar mills also makes excellent feed. Preparing feed involves mixing organic matter with cow dung, which should be finely ground for easier consumption. Biogas slurry can be a suitable alternative feed. To separate vermicompost from earthworms, spread the compost on a tarpaulin or burlap in sunlight. Sensitive to light, earthworms burrow deeper, making separation easy and harm-free. Tough or weed-infested materials should be avoided to protect the worms and maintain compost quality. Vermicompost is richer in nutrients than cow dung, containing 1–1.5% nitrogen, 0.9% phosphorus, and 0.4% potassium on average. It is also packed with beneficial microorganisms, growth hormones, and organic compounds, enhancing soil fertility. Vermicompost finds versatile uses in mulching, sustainable agriculture, electricity generation, and even eco-friendly brick production. This eco-friendly practice transforms organic waste into a nutrient-rich soil amendment, supporting sustainable farming by improving crop yields and soil health. Cattle manure remains the best raw material for vermicomposting. Recognized worldwide for its environmental benefits, vermicomposting is a cornerstone of sustainable waste management. By adopting it as part of a broader solid waste management plan, societies can make significant strides toward a greener, more sustainable future.

BACKGROUND

Vermicomposting is an eco-friendly and practical way to manage solid waste, offering a sustainable alternative to landfills. This simple yet effective process turns organic waste into high-quality manure, making it an excellent solution for dealing with agricultural waste [1, 2, and 3]. The fertilizer produced, enriched with nutrients from earthworm castings, is particularly beneficial for orchards and crop farming, supporting a healthier and more sustainable agricultural system. The process works by letting organic waste naturally break down, with the help of earthworms, into a rich, nutrient-dense fertilizer. Compared to traditional composting, vermicomposting is much faster and produces compost with a lower carbon-to-nitrogen (C/N) ratio, making it more effective. Earthworms play a crucial role in this process, breaking down organic material into vermicompost, a highly nutritious and soil-friendly substance. Studies have shown that vermicompost improves soil's ability to hold water, increases aeration, and enhances fertility, making it an excellent choice for farming [4,5]. The final product of vermicomposting is a well-textured, porous fertilizer that promotes microbial activity and improves soil structure. It helps plants grow better by retaining water and providing essential nutrients, all while reducing the need for chemical fertilizers and pesticides. This makes it a great option for organic farming, which focuses on maintaining the health of the soil and the environment. Earthworms contribute significantly to improving soil quality by breaking down organic materials and enriching the soil's structure [6,7]. This natural process makes the soil more porous, helps retain moisture, and boosts its nutrient content, all of which are critical for plant health and higher crop yields. Vermicompost is also cost-effective, offering a more sustainable and affordable alternative to chemical fertilizers [8-10]. Beyond farming, vermicomposting is an important tool for reducing waste and protecting the

environment. It minimizes the amount of organic waste that ends up in landfills, helping to lower greenhouse gas emissions. By enriching the soil and preventing erosion, vermicomposting also supports healthier ecosystems and sustainable agricultural practices [11, 12]. Vermicomposting is a simple, cost-effective way to recycle organic waste and improve soil health. It helps farmers grow more while reducing their reliance on harmful chemicals, all while contributing to a greener, more sustainable future for agriculture and the environment [13, 14].

METHOD

The production of vermicompost begins with the setup of a well-designed prototype model, tailored to create optimal conditions for the process. It starts with a sturdy tray measuring 30 cm by 80 cm (Figure 1), forming the foundation for composting. The base layer is carefully prepared using a mixture of sugarcane waste and cow dung, filling approximately 80% of the tray. This layer is then lightly sprayed with water to ensure the moisture levels are just right for effective decomposition. Once the base is ready, additional waste materials are gradually added, as demonstrated in Figure 2. This step illustrates the layered development of the composting material, showcasing how the process evolves over time. To provide a comprehensive understanding, Figure 3 offers a detailed description of the tray, including its dimensions (length, width, and height), along with an overall view of the composting setup. Figure 4 presents the prototype model fully loaded with all the essential materials, showcasing a balanced and well-prepared arrangement ready for the introduction of earthworms. Finally, as depicted in Figure 5, 2 kilograms of earthworms are carefully introduced into the model. This critical step initiates the vermicomposting process, as the earthworms begin breaking down the organic material into nutrient-rich vermicompost. By following these steps, the prototype model ensures an efficient, sustainable, and user-friendly approach to producing high-quality vermicompost, paving the way for eco-friendly waste management and enhanced soil fertility.

On my farm, I've established a scalable vermicomposting unit that has become a cornerstone of sustainable waste management and organic farming. Figure 6 captures the full strength of the earthworm species used in the process, highlighting their vital role in transforming organic waste into nutrient-rich compost. Figure 7 documents the purchase of 10 kilograms of *Eisenia fetida*, a species well-known for its exceptional efficiency in vermicomposting, and their introduction to the farm. As the composting unit progresses to its final stages (Figure 6), the smooth integration of the compost layers signals that it is primed for the introduction of *Eisenia fetida*. Approximately 2 kilograms of these earthworms are added to each prepared mixture, as shown in Figure 7. The farm features a combination of open plot beds and closed bed structures, providing flexibility and efficiency. Figure 8 showcases the closed bed system, which offers a distinct advantage: it enables the collection of Vermiwash, a nutrient-rich liquid that can be used as an organic spray to further enrich soil and plant health. The collection process is illustrated in Figure 10, emphasizing its importance in this sustainable system. The culmination of this process is seen in Figure 11, which presents 2 tons of high-quality vermicompost, ready to be applied to crops. This compost significantly enhances crop vitality and yields, marking a transformative impact on agricultural productivity. As the process concludes, the life cycle of *Eisenia fetida* is complete, with the spent worms naturally decomposing and enriching the soil further. Figures 13 and 14 beautifully showcase the results of this endeavor: a thriving organic plot of Golden Cilantro. These flourishing plants stand as a testament to the power of vermicompost, demonstrating its profound effect on soil health, plant growth, and overall agricultural sustainability. This project underscores the harmony between innovative practices and nature, offering a replicable model for sustainable farming. Figure 15 and 16 shows PH value of 5.71 and figure 16 shows electrical conductivity.

Fig. 1. Base Layer.

Fig. 2. Trash adding.

Fig. 3. Height of Tray indicating 50 cm.

Fig. 4. The Total tray is filled with input material.

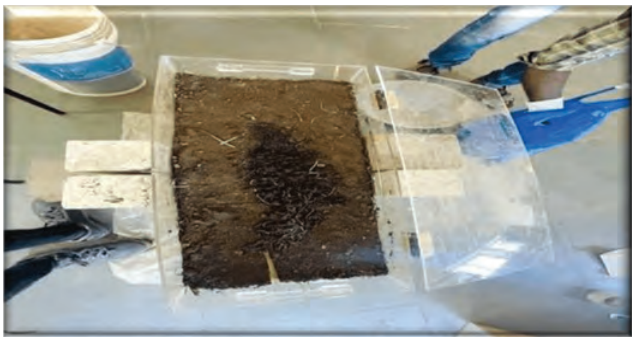

Fig. 5. Tray filled with Vermin.

Fig. 6. Group of Eisenia fetida.

Fig. 7. Packing of Eisenia fetida with moisture soil.

Fig. 8. Harvesting of the final product from the open bed

Fig. 9. Closed bed of sugarcane waste & cow dung.

Fig. 10. Vermiwash from closed bed.

Fig. 11. Final manure from vermicomposting.

Fig. 12. Died Eisenia fetida.

Fig. 13. Plant Golden Cilantro with Vermicompost manure.

Fig. 14. Organic Golden Cilantro Plot.

Fig. 15. PH Value

Fig. 16. Electrical Conductivity

RESULTS AND DISCUSSION

Results

The nutrient content of sugarcane trash, particularly manganese and iron, tends to increase during the summer rains due to natural oxidation and reduction processes. These rains play a key role in reducing manganese deficiency in sugarcane trash, enhancing its value as a resource. The period from June to October is critical for monitoring sugarcane trash nutrient levels, as it aligns with the peak sugarcane growth phase in India, driven by the monsoon season. During this time, the increase in soil moisture boosts the concentrations of manganese and iron in the trash. While soil moisture levels can vary throughout the year, other nutrients remain relatively stable during the summer and spring months. Consequently, June and July are considered

the best months for collecting sugarcane trash. By August, accessing the fields becomes more challenging due to crop growth and seasonal changes. This study compares the collection and analysis of sugarcane trash samples during the early summer months with samples taken later in the season. Notably, the nutrient content and the presence of earthworms in the trash increase by approximately 30% during the summer, further enhancing its suitability for plant growth. These improvements make sugarcane trash an excellent resource for boosting soil fertility and promoting healthier crop yields, underscoring its importance in sustainable agricultural practices.

The following are the advantages of vermicompost:

1. Improved Soil Fertility: Vermicompost enriches the soil with essential nutrients, promoting better plant growth and higher crop yields.
2. Enhanced Soil Structure: The addition of vermicompost improves soil texture, making it more porous and better able to retain water and air.
3. Increased Microbial Activity: Vermicompost boosts microbial activity in the soil, which helps decompose organic material, enhancing nutrient cycling and soil health.
4. Natural Fertilizer: It serves as an eco-friendly, natural fertilizer, reducing the need for chemical fertilizers and minimizing environmental pollution.
5. Better Water Retention: Vermicompost improves the soil's water retention capabilities, reducing the need for frequent irrigation and preventing waterlogging.

Discussion

To promote vermicomposting practices in agricultural fields, several essential steps are being taken to raise awareness and provide practical support to farmers. Awareness programs and training sessions play a key role, with various government organizations leading initiatives to educate farmers about sustainable practices, such as using sugarcane trash for vermicomposting instead of burning it. These sessions also introduce techniques like ammonization with urea, which transforms sugarcane trash into livestock feed while addressing environmental concerns. Burning sugarcane trash contributes significantly to climate change, and these programs aim to reduce this harmful practice by encouraging eco-friendly alternatives. One impactful strategy involves forming farmer groups with the support of the Agricultural Technology Management Agency (ATMA). These groups participate in discussions and lectures on techniques such as urea enrichment. Insights from this study reveal the nutritional benefits of sugarcane trash, particularly during the summer months, making it a valuable resource for both vermicomposting and livestock feeding. Among the methods introduced, urea ammonization has proven to be more effective than traditional urea treatment. This approach enhances the palatability and fiber digestibility of fodder, providing nitrogen in the form of protein, which benefits livestock. Government technical staff work closely with farmers, offering guidance on livestock feeding practices and dry fodder utilization. Their ongoing support ensures that farmers can confidently adopt and implement urea enrichment methods without confusion. To further ease the transition to sustainable practices, government organizations supply all the necessary materials for the urea enrichment process to interested farmers. These combined efforts empower farmers to adopt vermicomposting and sustainable waste management practices, improving soil health, reducing environmental harm, and enhancing agricultural productivity.

Table 1 shows the study focused on transforming sugarcane waste into nutrient-rich compost through a two-stage process involving microbial composting followed by vermicomposting. Initially, sugarcane waste exhibited a high carbon-to-nitrogen (C:N) ratio of 80:1, low nitrogen levels (0.5%), and a pH of 6.5. After microbial composting, significant improvements were observed, including a reduction in the C:N ratio to 25:1, an increase in total nitrogen to 1.2%, and a rise in phosphorus and potassium levels by 400% and 250%, respectively. The subsequent vermicomposting stage, using Eisenia foetida, further enhanced the compost quality. The C:N ratio improved to 10:1, indicating maturity and stability, while nitrogen content reached 1.8%. Phosphorus and potassium levels also increased significantly, making the compost highly nutrient-rich. Additionally, microbial activity was substantially elevated, with microbial counts rising from 10310^3 CFU/g in the initial waste to 10810^8 CFU/g after

vermicomposting. The pH stabilized at 7.5, and moisture content reduced from 65% to 45%, ideal for agricultural application.

This process not only demonstrated an effective way to recycle sugarcane waste but also produced high-quality compost suitable for sustainable agricultural practices, contributing to waste management and soil fertility enhancement.

Table 1:

Parameters	Initial Sugarcane Waste	After Microbial Com-posting	After Vermicom-posting	% Change
PH	6.4	7.1	7.4	-
Moisture Content (%)	64	49	46	-
Organic Carbon (%)	39	29	17	-54%
Total Nitrogen (%)	0.4	1.2	1.7	+260%
C:N Ratio	80.2	25:1	10:1	Improved
Phosp-horous (%)	0.1	0.5	0.8	+700%
Potassium (%)	0.2	0.7	1	+400%
Eisenia foetida growth	-	-	Observed	-

Fig. 16 shows graphical representation of nutrient composition of vermicompost produced

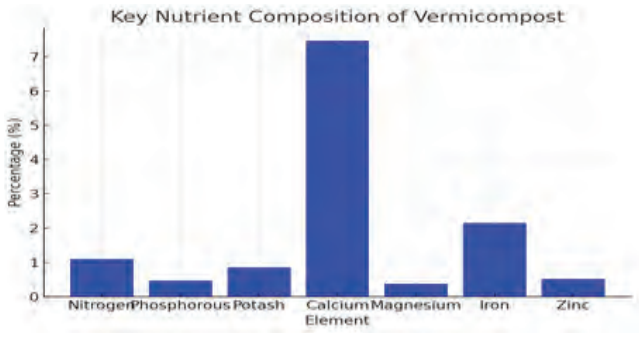

Fig. 17. Nutrient contents in vermicompost

Payback period calculation of plant installed:

1. Cost Calculation for 1 Bed:

- Sugarcane Waste (300 kg @ Rs/- 1/kg): Cost=300×1= Rs/- 300
- Cow Dung (700 kg @ Rs/- 4/kg): Cost=700×4= Rs/- 2800
- Total Input Cost for 1 Bed: Total Cost=300+2800= Rs/- 3100

2. Revenue Calculation for 1 Bed (in 3 months):

- Vermicompost (700 kg Rs/- ₹10/kg): Revenue from Vermicompost=700×10= Rs/- 7000
- Vermiwash (3 liters/day, Rs/- 5/liter for 90 days): Revenue from Vermiwash=3×5×90 1350
- Total Revenue from 1 Bed: Total Revenue=7000+1350=8350

3. Net Profit for 1 Bed (in 3 months):

Net Profit (1 Bed) = Total Revenue−Total Cost=8350−3100 = 5250

4. Net Profit for 20 Beds (in 3 months):

Net Profit (20 Beds) = 20×5250= 1, 05,000

Annual Profit (assuming 4 cycles per year):

Annual Profit=4×105000 = 4, 20,000

5. Payback Period Calculation:

1. Net Profit (1 Bed in 3 Months): Rs/- 5250
2. Net Profit (20 Beds in 3 Months: Rs/- 1,05,000
3. Annual Profit (20 Beds): Rs/- 4,20,000
4. Initial investment for 20 beds shade: 10 Lakhs
5. Payback Period: ~2.2 years (26 months)

Figure 17 shows graphical representation of payback period calculation of plant installed in my farm.

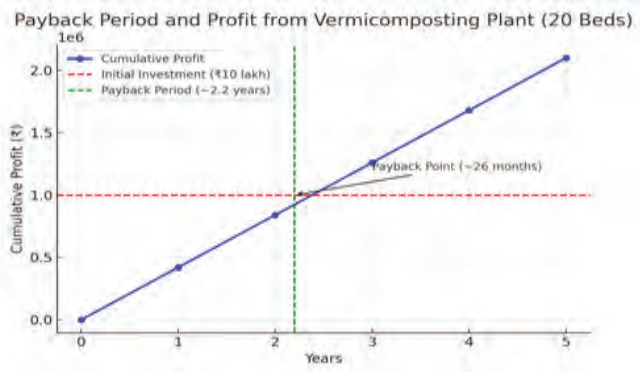

Fig. 18. Payback period representation of plant

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CONCLUSION

The disposal of industrial sludge poses a significant challenge, but an innovative and sustainable solution lies in vermicomposting, particularly for treating press mud. This study demonstrates that press mud can be effectively converted into stable, nutrient-rich vermicompost with significantly lower carbon-to-nitrogen (C: N) ratios. By blending press mud with cow dung in a 1:1 ratio, or up to 50% cow dung, and processing it with the help of earthworms like *Eisenia foetida*, high-quality, value-added compost can be achieved. This method offers a dual advantage for sugar mills: it transforms industrial waste into a valuable resource while significantly reducing the volume of waste destined for landfills or open dumping. Vermicomposting with *Eisenia foetida* is particularly effective in breaking down sugarcane bagasse and leaves. However, nutrient depletion during the process leads to a gradual reduction in the worm population. While the 1:1 ratio of press mud to cow dung decomposes faster, a 70:30 ratio (press mud to cow dung) is more economical and practical for large-scale waste management. The process also generated essential macro and micronutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), copper (Cu), zinc (Zn), and iron (Fe), which are vital for plant growth. Looking ahead, the scope for using other agricultural organic waste in vermicomposting offers promising opportunities for sustainable waste management. Burning sugarcane trash in fields not only harms human health and the environment but also exacerbates atmospheric pollution, creating challenges for farmers. Vermicomposting provides a sustainable alternative by converting agricultural waste into a valuable product that enhances soil productivity, reduces reliance on chemical pesticides, and mitigates environmental harm. For industries, vermicomposting represents an economical pollution abatement technology, turning waste into wealth. It also contributes to the national economy by reducing the need for purchased agricultural inputs, preventing wasteland formation, and supporting rural economic growth. This study underscores the potential of vermicomposting as a transformative solution for industrial and agricultural waste management.

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Creative Approaches to Reimagine Abandoned Industrial Structures

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ABSTRACT

Industrial building is a symbolism of the industrial era which also plays an important role in contributing the GDP (Gross Domestic Production) of any country. But as cities evolved these industrial buildings are become under used and are often left neglected as a result these are left abandoned. But still there are few buildings possessing immense potential for the reuse. The practise for reusing the structure not only preserves the cultural and historical significance of the building but also meet the contemporary needs such as: housing, offices, cultural hub and commercial spaces. Recent studies shows that adaptive reuse not only increases the life span of any structure but also, promotes sustainability, reduces urban sprawl and revitalise community. This paper examines the process of repurposing disused industrial sites, exploring the challenges, opportunities, and benefits associated with such projects.

Through a comprehensive review of case studies, such as: Dhan Mill, Chhatarpur, New Delhi; Alembic Museum, Vadodara and Delhi Flour Mill, New Delhi identifies successful approaches to transforming outdated industrial structures into functional spaces for residential, commercial, and cultural purposes. These projects tell how adaptive reuse blends the historic architecture with modern functionality. It also reduces the carbon footprint associated with new construction, economic revitalisation and promotes sustainability. By redesigning/ repurposing these structures architects and urban planners contribute to industrial preservation. Also, a survey was conducted in which 81 people from different age group as well as from various profession participated in order to understand the perception of people about adaptive reuse of building and its advantages. Furthermore, this paper also talks about the various factor which contributes in successful adaptive reuse projects are as follows: site selection, architectural design, regulatory framework and community engagement. In conclusion, adaptive reuse is a forward-thinking strategy in architecture that balances the preservation of cultural heritage with the raising demands of modern urban life. As cities faces the problem of urbanisation and environmental sustainability, adaptive reuse is the strategic solution to all the problems.

***KEYWORDS** : Adaptive reuse, Industrial heritage, Urban sprawl, Sustainable practice.*

INTRODUCTION

Adaptive reuse is the method of sustainable renovation as it improves and increases the life of any structure. It is not only a process of using usable component of any building for new use, but also a method to preserve the cultural heritage. It is just a process of renovating old and abundant building without losing its cultural heritage and historical values and creating the structure according to the requirement of the time (Zahraa Adil Abdulameer, 2020).As the increasing environmental conditions, rising the demand and increasing cost of the construction material have made the need of the adaptive reuse as a part of an architectural doctrine. As all the financial conditions such as: increasing cost of construction material, minimum availability of the land etc. have made constructing new

buildings expensive, as a result adaptive reuse have become an alternative for urban renewable projects over time (Didem TELLI, 2018). Adaptive reuse is the principle which enhances the quality of life of the structures without burdening the future generations. By repurposing the existing abandoned structures for new purpose and functioning not only maximises the usage of the built environment but also reduces the need of new resources. This method not only prevents the demolition of the structure but also reduces the need of new material as well the carbon emission. Beyond environmental benefits, it also provides the economic benefits. As a result, it plays a vital role in advancing the goals of sustainable urban development (Hample, 2020). Adaptive reuse of a building helps in making a new building by changing its performance, capacity and function according to the current requirement. The increasing demand for new building according to the trend and due to land scarcity results in demolition of an old structure (Dilantha De Silva, 2016). Therefore, Adaptive reuse is an opportunity to reuse the obsolete facilities such as existing infrastructure and materials of structure to promote sustainability and smart growth of the cities in order to focus upon the redevelopment in the cities in order to decrease the urban expansion (Cantell, 2005). Currently, India is dealing with the struggle for environmental sustainability. By using RRR method-Reduce, Reuse and Recycle which encourages in recycle any and everything including vehicles, boxes, plastic, bottles, glass and even buildings. But if anything is not recyclable it is advice to be reuse it either for the same purpose or for a new one. Similarly, buildings are also given second life by the method of reusing in which any building which is no longer is repurposed such that it serves the new function as well as reduces the environmental impact (Ar. Shreya Chandrakar, 2022).

LITERATURE REVIEW / THEORETICAL BACKGROUND

Industrial Building Heritage

Many historically significant industrial buildings were demolished due to modernisation, change in economy and needs of the people. Therefore, this term came out to avoid the destruction of old industrial building. The terms "Industrial Heritage" and "Industrial Archaeology" were never clarified for a long while, "Nizhny Tagil Charter for the Industrial Heritage", published in 2003 set the definition for "Industrial Archaeology" as "an interdisciplinary method of studying all the evidence, material and immaterial, of documents, artefacts, stratigraphy and structures, human settlements and natural and urban landscapes, created for or by industrial processes" and "Industrial Heritage" (Didem TELLI, 2018)Industrial building is building or part thereof wherein products or material are fabricated, assembled, or processed as well as where energy is generated, transmitted and used which includes assembly plants, laboratories, power plants, refineries, gas plants, mills, workshops, mines, warehouse and factories (Tanya Gupta, May 2023). It plays an important role which comprises of more than just the structures that formerly held industrial operations; they also include the surrounding area, machinery, and industrial archaeology, as well as other evidence of manufacturing and other processes. It helps in revitalizing deteriorating or decaying places by enhancing urban character and identity, boosting facilities, and taking steps that promote economic development. Repurposing abandoned industrial structures can provide psychological stability to communities facing sudden loss in income and employment (Negi, 2023). Heritage is important because it helps to shape our identity also, becomes part of where we are. It improves the value, talks about our past and how society is evolved. It helps to examine our culture and traditions it also enables us to create awareness about past (Shreya Chandrakar, 2022).

Industrial Revolution in India

Before Independence

India underwent de-industrialization during late 18th and early 19th centuries due to its two main reasons which are as follows:

1) The decline of the Mughal empire, which resulted the expansion of the revenue farming, increasing the rent, and declination of regional trade within the sub-continent, which significantly reduced the productivity of foodgrain agriculture.

2) Agricultural productivity in India improved under the relative stability of British East India Company rule and grain prices became more stable, the Indian textile industry suffered. By 1860, India had

become a net exporter to a net importer of textiles which marked the end of de-industrialization (David Clingingsmith, 2004).

The industrialization in India emerged in the late 19th century, primarily in the textile industry. British entrepreneurs established textile mills in India to take advantage of cheap labour and availability of cotton. These mills were primarily located in Bombay (Amit Chawla, 2022). Whereas, British industries such as East India Company were supported by foreign ruler which led to the discontinuation of Indian industries (Renu Kumari, 2022).

After Independence

After independence industrialisation was seen as the key to remove poverty. It also offered improved upon the economy of the nation from technical progress. Since, he believed that the agriculture and exports alone won't help in improving the economy. Indian governments taxed agriculture heavily and focused upon developing domestic industries. This meant giving more importance to heavy industry and reducing reliance on imported goods. India launched five-year plans in 1951, under the influence of first Prime Minister Jawaharlal Nehru and two subsequent five-year plans were formulated till 1965.The first eight-year plans focused upon growing public sector with large number of investments in basic and heavy industries (Jana Hambrock, 2023-2024).

Industrial Heritage Conservation

Industrial Heritage Conservation is just a "movement" which helps us realise the importance of the sites in the contemporary world, it's about spreading awareness and preserving it in the best possible ways. Historic structures should be restored by inspecting the sites, identifying their cultural significance, their construction techniques and technology and also by understanding the type of damage and defect (Shreya Chandrakar, 2022).

NITI Aayog delivered a report named 'Improving Heritage Management in India to look after and understand the existing challenges for heritage, it provides a roadmap for the branding of India's built and archaeological heritage. The report includes a classification of built heritage, acknowledging industrial heritage as an important category among historic buildings and sites. Additionally, NITI Aayog's national-level research project, 'Challenges Faced in Heritage Management in India and Policy Imperatives', aimed at assessing the state of both protected and unprotected cultural heritage across the country, also highlights industrial heritage as a significant component in the heritage listing process (India, 2018-2022).

Adaptive Reuse

Adaptive reuse referred to find a new use for an existing building. It is a "process by which older buildings with structural integrity are developed for commercially viable new uses". It first emerged as a strategy for preventing the destruction. It involves "a wide range of repairs or adjustments to an existing building that allows to fulfil current needs while maintaining aspects of the past". Hence, adaptive reuse is part of rehabilitation. Also, adaptive reuse is sometimes referred to as adaptable use (Negi, 2023).

The concept of adaptive reuse is in today's world is a major topic of discussion. Global warming, a growing population, and growing needs, is increasing day by day. Not only this, the building sector also adapts and find ways to accommodate the growing number of people in cities and decreasing emissions. "Historical buildings have significance and they are the memories of the society and are often in advantageous locations in the city centres which provide social benefits such as intrinsic heritage values that they have" (HAMPEL, 2020). Adaptive reuse means to engender a fresh purpose to an existing structure. For e.g. Let's Imagine an old shoe store turned into a bar, an industrial factory repurposed into a museum, a dilapidated building transformed into a lush affluent bungalow. For the restoration of a project, financial means and construction techniques must adhere exponentially in renovating the structures (Inscape, 2021). In India, adaptive reuse projects can also face cultural challenges, especially if the building or site has significant cultural or historical value. Community members may have strong emotional ties to the building or site, which can create resistance to change. (Shreya Chandrakar, 2022)

Importance of Adaptive Reuse

- Heritage and Cultural Preservation: There are various industrial buildings which possess cultural

and heritage value. By adaptive reuse, helps in cultural preservation of site which is left unused or decay for many years.

- Reducing Urban Sprawl: As with the passage of time, needs and demands of the people are rising but the land available for construction is in limited. Therefore, by using the method of adaptive reuse it reduces the urban sprawl.
- Social Benefits: By using means of adaptive reuse, it contributes in increasing socialisation among the people by creating spaces which offers cultural activities, events and cultural gatherings.
- Economic Benefit: Adaptive reuse not only promotes social benefit but also promotes economy by creating new opportunities for business and providing employment to unemployed people.
- Promoting Sustainability: As it reduces the consumption of resources as well as energy emissions by reducing the need of construction which reduces the environmental impact associated with demolition. (Shreya Chandrakar, 2022)

Challenges occur during Adaptive Reuse

- Financial Challenges: In India, adaptive reuse projects can be expensive, especially when compared to new construction projects. Retrofitting an existing building or site for a new use can cost significantly more than building from scratch. Moreover, financial return on investment may not be as immediate as with new construction projects, making it harder to secure funding.
- Regulatory Challenges: Adaptive reuse projects in India can also face regulatory challenges, especially if the structure or site is significant historically or culturally or is situated in a protected area. Historic preservation is subject to certain rules set out by heritage organisations.
- Cultural Challenges: In India, adaptive reuse projects can also face cultural challenges, especially if the building or site has significant cultural or historical value. Community members may have strong emotional ties to the building or site, which can create resistance to change. (Shreya Chandrakar, 2022)

Existing Policies

The development of any urban area is dependent on the development plan structured for it. Thus, the various Government development plans that can be applicable on the area under study were analysed to identify the shortfalls.

Table 1. Existing Policies on Adaptive Reuse of any building

Operational Guideline/ Regulation/ Legislation	Organization	Month& Year of Publication	Salient features/ Guidelines	Gaps/ Remarks
Handbook of Conservation of Heritage Buildings	CPWD	Jul 2013	The handbook provides guidelines to protect the buildings, sites, furniture, interiors, landscapes etc. of heritage value.	The handbook covers the protected and the unprotected sites and properties with heritage importance but not with the historic importance. Also, it does not specify the HULs.
Operational Guidelines for (HRIDAY) Heritage City Development and Augmentation Yojana	Ministry of Urban Developm nt, Govt. of India	Jan 2015	The guidelines deal with the heritage and historic cities and landscapes and their redevelopment, protection and conservation.	The guidelines, as of now, are limited to a specific number of cities only and cannot be applied on any other city or HUL.

Charter for the Conservation of Unprotected Architectural Heritage and Sites in India	INTACH	2004	The charter is dedicated to the identification and protection of the unprotected sites, monuments, antiquities and landscapes.	The charter is to an extent applicable on the area under concern but does not specify the colonial cantonment towns as a genre.
Swadesh Darshan: Scheme Guidelines for Integrated Development of Theme-Based Tourist Circuits in the Country	Ministry of Tourism, Govt. of India	2014-15	The scheme is dedicated to the building an infrastructure so as to promote tourism, redevelop and maintain the heritage sites and follow community-based development for the same.	The scheme does not consider the historic colonial settlements.
PRASAD (National Mission on Pilgrimage Rejuvenation and Spiritual Augmentation Drive) Scheme Guide	Ministry of Tourism	2014-15	The mission focuses on the capacity building and development of the pilgrimage t own of India so as to achieve art tourism infrastructure and facilities in these towns.	The mission focuses only on the towns with religious importance and is not applicable to Colonial Cantonments.
JNNURM Scheme Guidelines	Ministry of Housing and Urban Affairs	2012	The scheme deals with the overall development of Indian Cities creating economically productive, efficient, equitable and responsive cities by a strategy of upgrading the social and economic infrastructure	The scheme was a term bound project and did not consider the Cantonments as a specific target.
(AMRUT) Atal Mission for Rejuvenation and Urban Transformation	Ministry of Housing and Urban Affairs	2015	This scheme was in continuation of JNNURM	The gap still remained regarding the acknowledgement and development of Colonial Cantonment towns as HUL
Smart City Mission	Ministry Urban Development	2015	Urban renewal and retrofitting program	Does not acknowledge colonial cantonment towns as HUL

(Source: Author)

CASE STUDIES

Introduction

The paper will provide us a deep understanding on how architects and planners have creatively reimagined and built-up these spaces. The following case studies: Dhan Mill, Chhatarpur, New Delhi; Alembic Factory, Vadodara, Gujarat and Delhi Flour Mill, Roshana Road, New Delhi will tell us about the challenges and solutions involved in transforming industrial buildings into new functional space, such as: residential lofts, art galleries, co-working spaces, or community centres.

- CASE 1: The Dhan Mill, Chhatarpur, New Delhi

Dhan Mill which is located in Chhatarpur, New Delhi is one of the good examples of adaptive reuse of an industrial building. It has an area of around 13000 sqm. Initially, the building was built in year 1960 and was used for the industrial purpose (i.e. for paddy production) later due to advancement it got declined in 1990.Then, it was turned into a commercial space in 2010 as a MNC's warehouse. Since 2015, space has been used for recreational purpose including: design studios, cafes, boutique spaces and event spaces. Firm named 'The Portal 92' have reused this abandoned industrial area and converted into a recreational space (Portal 92, 2024).

Table 2: Comparison of Building Old v/s New

Parameters	Inferences	
	Old	New
Surrounding Context	The site found itself encircled by a medley of privately owned factories.	The transformation of the site into an institute has triggered a ripple effect in its surroundings, gradually shaping them into vibrant commercial spaces.
Function	Manufacturing plant of Dhan (Paddy)	The former industrial site has been repurposed into a commercial space. These include boutiques, showrooms, cafeterias and co-working space.
Architectural Style	No defined style	Modern style
Structural system	Brick walls, GI sheet, Steel columns and beams	Most of the structural system has been reused
Material	Brick and Steel	Brick, Steel and Concrete

(Source: Author)

- CASE 2: Alembic Factory, Vadodara, Gujarat

Alembic industrial building in Vadodara have area of 1300sq.m has 110th year of existence built in year 1907, it underwent several changes. Originally it was used for chemical production. Later, it underwent into a transformation and shifted from its original purpose. The evolution of this space continued over time. Later, in year 2019 it was transformed by Karan Grover and Associate into cultural center encompassing of art studios, exhibition spaces, and various ancillary facilities including a library, AV room, and a cafe. This adaptive reuse has given new life to the venerable historic buildings and its legacy (Paula Pintos, 2019).

Table 3: Comparison of Building Old v/s New

Parameters	Inferences	
	Old	New
Surrounding Context	The site found itself encircled by a medley of privately owned factories.	The transformation of the site is now majorly surrounded with recreational spaces, housing and commercial spaces.
Function	It was a Perma nautical factory mainly producing penicillin, a groundbreaking contribution to medicine.	The former industrial site has been repurposed into a Cultural Centre. Showcasing the cultural past of Vadodara. It incorporates exhibition space, cafeterias, library etc.
Architectural Style	No defined style	Contemporary Style
Structural system	Brick walls, GI sheet, Steel columns and Arches	Most of the structural system has been reused
Material	Brick, Truss and terracotta tiles	Brick, New Mangalore tiles and Concrete

(Source: Author)

- CASE 3: The Delhi Flour Mill, Roshana Road, New Delhi

The Delhi Flour Mill, located on Roshanara Road in New Delhi, is one of the oldest flour mills in India, established in early 20th century. Initially, it was settled by the Britisher's in 1986 which was then bought by an Indian trader in 1947 and shut down in 2015. It has

an area of 18000 sqm. It plays significant part of the city's industrial heritage, representing the early phases of mechanized grain processing in India. Currently, it is owned by Mohit Jain and as industries have shifted and flour milling has modernized, this industrial site, now underused or abandoned, provides an interesting opportunity for adaptive reuse.

Structural Analysis: The Original roofing material was Mangalore tiles and GI sheet. It has been damaged due to weather. So, it needs to be replaced by the new ones. Circular steel columns of 10" Dia were used in the existing structure. The columns still have strength and can bear load. Steel windows are in good shape, size and condition which could be reused. Mostly window glasses are broken. I section steel beam of cross-section (24"X 10") are provided of 15mm thickness. It also enhances the structure stability. Wooden Flooring is damaged/ broken with lot of holes in the floor. The wooden flooring needs to be changes with matching wooden materials. The present conditions of the Door frames is damaged / decayed due to termite weather effects and need to be replaced.

DATA ANALYSIS

There were 81 people from various profession such as: architects, designers and planners participated in the survey in which 41 people were ranging from 45-54 yrs, 10 people were ranging from 55-64yrs,13 people were ranging from 18-24yrs and 13 people were ranging from 35-44yrs. The detailed explanation of all the responses which received from different people are given below:

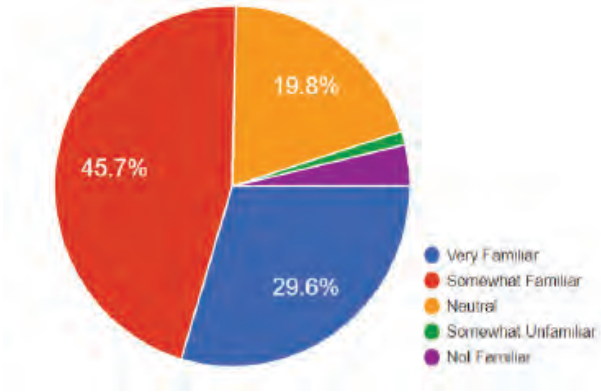

Fig. 1: indicates that 26.6% of the respondents were very much familiar and 45.7% were somewhat familiar with the topic of adaptive Reuse

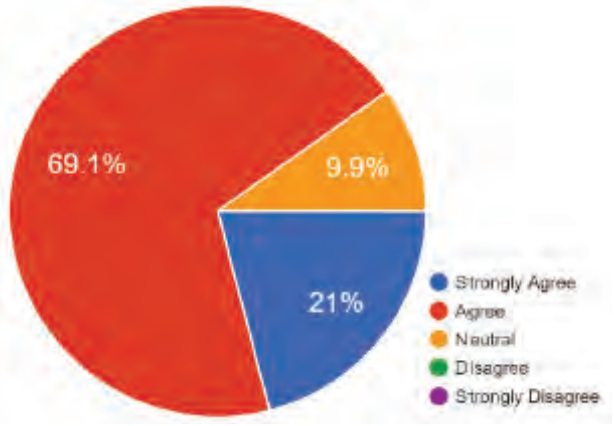

Fig. 2: indicates 69.1% agrees on repurposing old building for a new function whereas, 21% people strongly agree to this

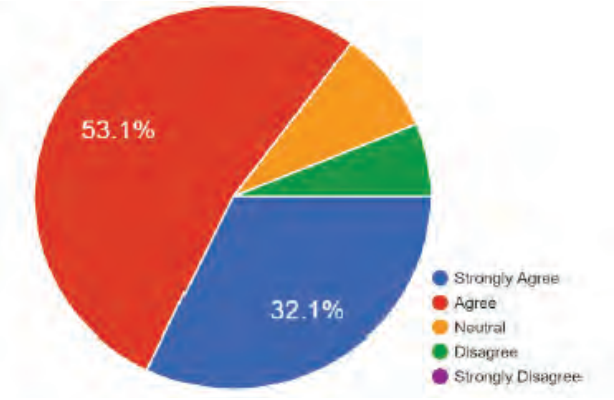

Fig. 3: talks about that 53.1% people agree that role of structural elements helps in preserving the authenticity and 32.1% strongly agrees to this.

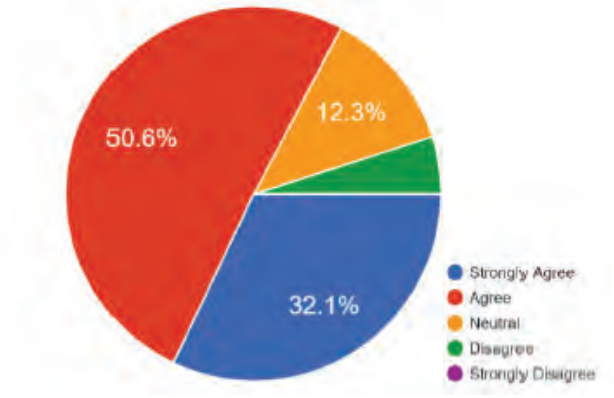

Fig. 4: says that 50.6% people agrees that adaptive reuse enhances the property value and 50.6% people agrees and 12.3% people were neutral. disagreed with this

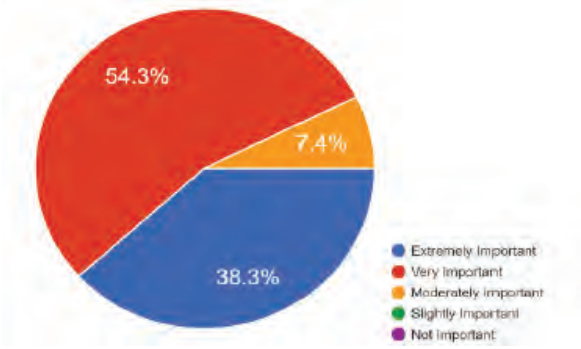

Fig. 5: talks about the importance of integration of sustainable practices like: incorporating energy- efficient system, green material. In which it was very important to 54.3%, and was extremely important to 38.3% people whereas, moderately important for 7.4% people

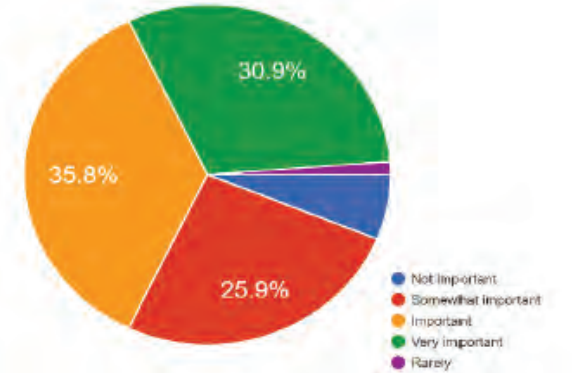

Fig. 6: talks about the maintenance of the historical characters of an industrial building during adaptive reuse. In which 35.8% people say it is important and 30.9% people marked very important, 25.9% people believe it was somewhat important

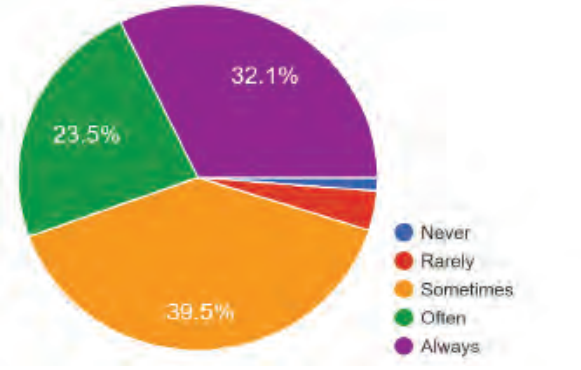

Fig. 7: talks about believing that whether industrial building is a good way to preserve cultural heritage. In which 32 people agree to sometimes whereas, 32.1% people agree to always, 23.5% people agree to often, 3% people agree to rarely

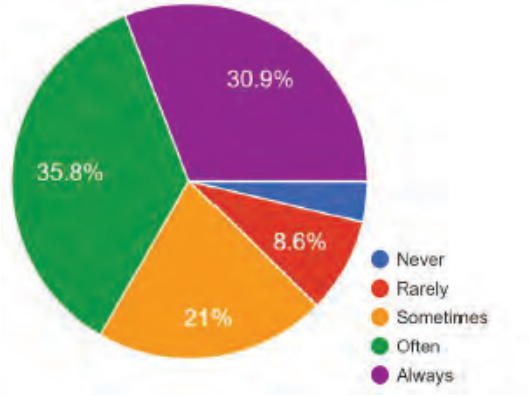

Fig. 8: talks about believing that adaptive reuse projects can contribute in combating climate change. In which 35.8% people agree to often, 30.9% people agree to always, 21% people agree to sometimes and 8.6% people agree to rarely

CONCLUSION

This research mainly focuses on preserving the past of an industrial structures by the means of adaptive reuse. Through various research papers, articles and books we can conclude that 'Adaptive Reuse' refers to the process of reusing an old building structure for a different purpose other than the initial purpose for which it was built or designed. The main aim of adaptive reuse of industrial buildings is transforming the once proud structures into new uses that serves different purposes while retaining their historical, architectural, and cultural value. Not only this adaptive reuse of any building including industrial buildings aligns with the sustainability goals, community engagement and positive social change in urban environments.

Through the examination of the above survey, it is evident that adaptive reuse offers significant benefits in terms of sustainability, economic revitalization, and cultural preservation. The analysis highlighted that while adaptive reuse can reduce environmental impact by minimizing construction waste. In order to facilitate the successful project of adaptive reuse, this paper possess various guidelines, policies for architects, designers and urban planners. Basically, these guidelines aim to provide a bridge between preservation of architectural heritage to the need for modern functionality which ensures that new uses are relevant to the original context. Through the above mention case studies and

literature review there are various possible conservation of different types of buildings.

This paper synthesis about the preserving of industrial building and reusing the old abandoned industrial building, an important aspect of architectural practice that addresses sustainability and urban regeneration. But it is not limited till here, there are various other historical buildings and monuments like: castles, baoli, residential building, civic buildings etc. which were once the very proud structure. But just like humans' buildings too have the life, so with the passage of time they have been left abandoned. But through adaptive reuse they can be conserved which also represents the cultural and historical significance.

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PMSG-WECS Grid Stabilization and LVRT Enhancement using Fuzzy-Driven DVR Technology

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ABSTRACT

Harnessing energy from Renewable Energy Sources (RES), like wind energy, and delivering that energy to the electrical grid is critical. The proposed method involving Wind Energy Conversion Systems (WECS) utilizing a Permanent Magnet Synchronous Generator (PMSG) offers a resolution for this issue. The PMSG used in wind energy conversion has capability of generating high power densities. The DVR is equipped to get rid of voltage fluctuations and maintains grid stability under varying sag conditions. The DVR is incorporated with Fuzzy Logic Controller (FLC) to ensure precise voltage regulation. The isolated flyback converter regulates output power by minimizing the interferences. The 31- level Cascaded H-Bridge Multilevel Inverter (CHB-MLI) reduces voltage stress and harmonic distortions that results in high power quality waveforms and supply the power to the grid. The presented method is applied in MATLAB Simulink and attains a Total Harmonic Distortion (THD) of 2.98%. Thus, the effectiveness of the proposed approach is enhanced by LVRT capability and regulates the grid volatge stability under various operational conditions. The proposed work provides relaible and efficient solution for grid connected wind power systems.

KEYWORDS *: RES, WECS, PMSG, LVRT, DVR, FLC , PWM, Isolated flyback converter, 31-level CHB-MLI, Grid.*

INTRODUCTION

The demand for energy globally is continuously rising because of population growth, increased per capita energy consumption, and rapid industrial development. The applicability of traditional fossil fuels is limited. Consequently, the usability of RES such as solar, tidal, ocean, wind, biogas etc. [1-2].Overall, wind energy stands out as one of the most promising sources. A WECS includes wind turbines, a control system, and generators that convert the energy captured from the wind into mechanical power that turns the rotor shaft. [3].The energy conversion of the WECS highly relies in the effective execution of controllers and harmonic filters.

The PMSG based WECS are commonly used in the generation of power because of its simple structure, low cost, simplicity of implementation and minimal maintenance. In transmitting power, grid fault triggers many issues in the network [4-5].To control energy flow in a PMSG-based wind energy conversion system (WECS), an automated control strategy is required to maintain a stable DC-link voltage under changing conditions to achieve low voltage ride-through (LVRT). The LVRT has the ability of keeping connected through

the grid fault and gives reactive power to reinforce the grid [6]. However, due to the electrical phenomenon of generators, the power quality issues generated from unbalanced conditions are enhanced by using DVR. The DVR has the adaptability to reduce the voltage variations and it is presented between the supply and the load of the power distribution system [7].

In steady state condition, DVR does not require any supply or receive real power. But, in practical conditions, DVR need to be maintained at constant voltage ratings without any compensations. To enhance the performance of the DVR, control strategies need to be integrated [8]. The DVR output is controlled by controllers such as PI controller. The PI controller generates the control signal by the weighted sum of error signal. However, PI produces non-linearity in the output waveform [9]. Henceforth, Fuzzy logic controller is integrated to enhance the performance of DVR by improving the voltage stability and power oscillations are minimized.

The output power form the transformer is AC that is converted into the DC by PWM rectifier to drive the grid circuit. To efficiently send the power to the grid without any harmonics high level inverters are employed. The isolated fly back converter reduces electromagnetic interference and regulates constant power to inverter. The MLI inverters are used to produce high quality power waveforms [10]. There are various types of MLI such as five-level, seven-level, thirteen-level, seventeen level etc.

The five-level inverter produces high frequency output voltage using six switches and six gate drivers. However, the five-level inverter has complex PWM control techniques and issues with voltage stabilizing [11]. The seven level inverter produces optimum quality waveform than five-level inverterwith diminished harmonics. Still, regulating capacitor voltages in real-time is critical [12]. The thirteen-level inverter require a single source to operate and produce 13-level waveforms. Despite, it needs increased control strategies for producing accurate switching signals [13].The seventeen level decreases the complexity and computational cost. It offers various switching levels under fewer switching device. Due to high risk of component failures, computational complexity gets increased [14-15]. The proposed 31-level CHB-MLI comprises of multiple dc sources provides scalability and reliability suitable for operation with WECS. The CHB-MLI consists few number of capacitors and diodes with other traditional techniques. The contributions of the proposed work are:

i) The power quality is enhanced and the voltage fluctuations are mitigated by using DVR.

ii) High power quality AC waveforms with reduced threshold harmonics is generated by the integration of 31-level CHB MLI.

PROPOSED SYSTEM DESCRIPTION

A comprehensive system is developed for enhnacing the PMSG based WECS by ensuring the stability of the grid and LVRT capability. The diagram of the proposed work is illustrated in Fig. 1.

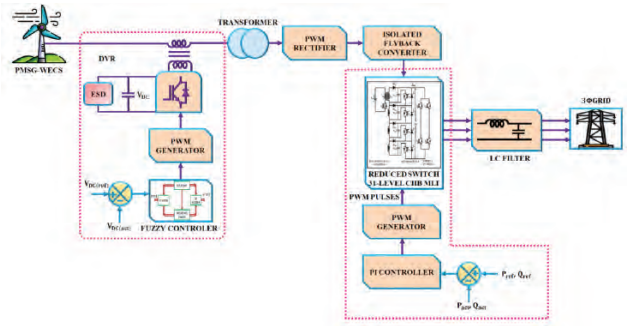

Fig. 1: Block diagram of the proposed model

The wind energy is converted into electrical power, by PMSG based WECS. The DVR is integrated for miltigating the voltage sags and ensures stable DC volatge. The Energy Storage Devics (ESD) supplies energy to attain stability during transitory events. The fuzzy controller works by comparing the actual voltage and reference voltage . It assures accurate DC voltage regulation by dynamically controlling the parameters and produces the control signal. The PWM generates the pulses from the control signal attained by the FLC. The power gnerated from the PMSG is passed through the transformer to PWM rectifier that is reponsible for converting AC power into stable DC-link power. The isolated flyback converter produces isolated output voltage by minimizing interferences and fed into the 31-level CHB MLI guarantees high quality AC power waveform with reduced harmonics. The high frequency

components are filtered out by LC filter. This system incorporates sophisticated control methods to ensure efficient performance, maintain grid stability.

PROPOSED SYSTEM MODELLING

PMSG based WECS.

PMSG comprise of stable flux that has a permanent magnet. It is more preferrable than the induction motors because it behaves like a AC wind generator for WECS with compact size, high power sensity and need for gear box eliminated. PMSG is modelled using d-q reference frame and illustrated in the Fig.2

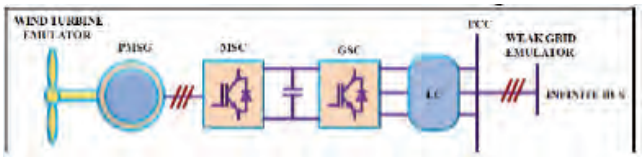

Fig. 2: PMSG-based WECS configuration

The mathematical representation of voltages of a PMSG is expressed in the synchronous d-q reference frame. The cross-coupling effect in d-q axis voltage is expressed as:

$$V_s^d = R_s i_s^d + l_s \frac{di_s^d}{dt} - \omega_e l_s i_s^q \quad (1)$$

$$V_s^q = R_s i_s^q + l_s \frac{di_s^q}{dt} - \omega_e l_s i_s^d + \omega_e \theta_d \quad (2)$$

The resistance of the PMSG stator windings is R_s and the inductance is l_s. The stator (d-q) direct and quadrature axis voltage and current are V_s^d, V_s^q, i_s^d, i_s^q respectively. The magnetic flux is ω_e and electric angular speed is θ_d.

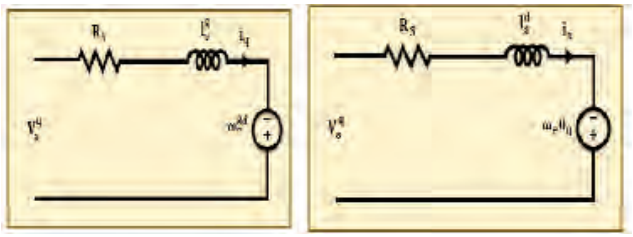

Fig. 3: PMSG mathematical model for d-axis and q-axis

The Fig.3 displays the d-axis and q-axis equivalent circuits respectively. The PMSG is a good option for WECS provides constant frequency of power. The power attained is fed into DVR for precise power control.

Dynamic Voltage Resistor

DVR equipment is essential to enhance the power quality and acts as a power compensator to compensate increased/reduced volatges. The voltage sags are common quality issue in the distribution network. To prevent from theses issues, DVR is utilized. The DVR is in series connection, the source voltage is V_s, the source reactance is X_s, DVR injected voltage is V_{sc} anf the effective resistance of the load is X_L.

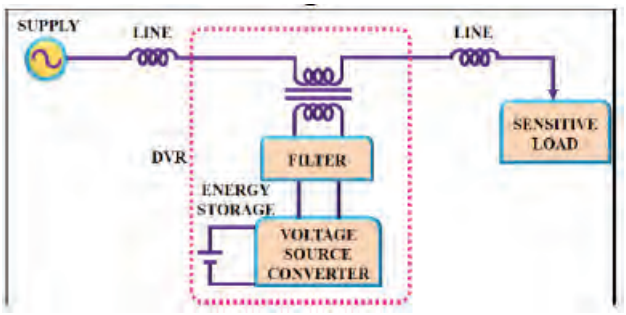

Fig. 4: Schematic diagram for DVR power system

The control system, detects the voltage reduction in the source side by regulating the switches and the voltage reduction is compensated by generating required voltage from the DVR. In normal condition, $\bar{V}_p$ fault reduces,

$$\vec{V}_L = \vec{V}_s - jX_s\vec{I}_L \quad (3)$$

The voltage phasor on the load side is $\vec{V}_L$ and the normal line current is $\vec{I}_L$. If fault arise in the source, $\bar{V}_p$ decreases and the source volatge is expressed by $\bar{V}_{avg}$. If series compensation is absence,

$$\vec{V}_p = \vec{V}_L = \vec{V}_{avg} - jX_s\vec{I}_L \quad (4)$$

The load side voltage $\vec{V}_L$, bus voltage $\bar{V}_p$ and load current under voltage sag $\vec{I}_L$. To prevent the load from voltage sag, DVR applies V_{sc} to the grid in series to attain the load voltage to the pre-fault level,

$$\vec{V}_L = \vec{V}_{avg} - jX_s\vec{I}_L + V_{sc} \quad (5)$$

Based on the control technique, the reference voltage varies. The Fig.5 to Fig.7 shows different phasor diagrams of different control approaches.

Fig.5 illustrates the pre-disturbance stage, the DVR makes compensation such that, the load voltage is modulated with the same level of phase and magnitude.

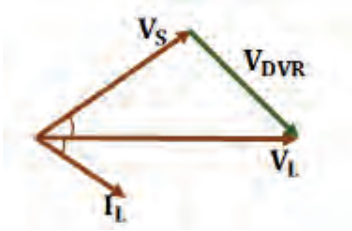

Fig. 5: Pre-disturbance stage phasor diagram

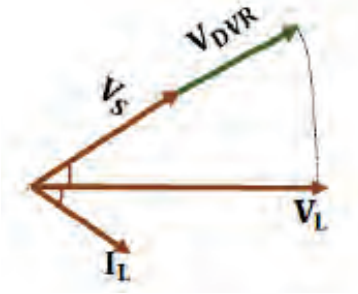

Fig. 6: In-phase stage phasor diagram

Fig. 6 depicts the in-phase approach phasor diagram. the voltage with same phase as post-disturbance voltage is applied by the DVR.

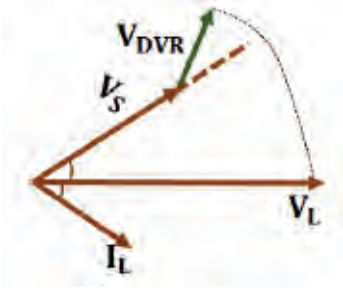

Fig. 7: Minimum phase stage phasor diagram

Fig.7 shows the phasor diagram of minimum phase approach. It is used to minimize the active power to the grid. The 90^0 phase difference voltage is applied with the line current, thus decreases the active power supply to zero. The DVR is equpped with FLC strategies for attaing accurate voltage control under varying operational conditions.

Fuzzy logic controller.

The non-linearities present in the power systems such as irregularities and exposure to network disturbances is handled by using FLC.

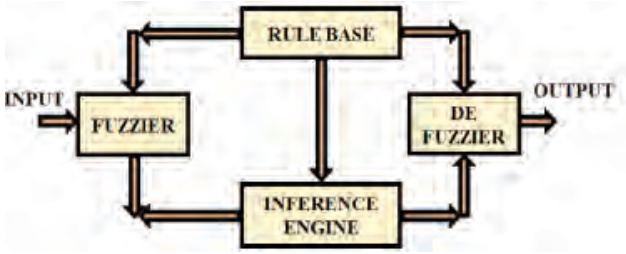

Fig. 8: Fuzzy logic controller

Fig. 8 shows the schematic structure of FLC. It is composed of three main components: Fuzzier, interference engine and Defuzzifier.

Fuzzifier: The two inputs from the range 0 to 1 is taken into the fuzzifier, where the Membership Function (MF) takes place.

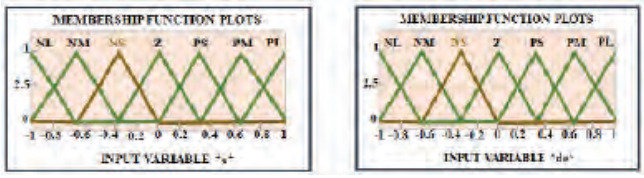

Fig. 9: MF of Input variable "e", "de"

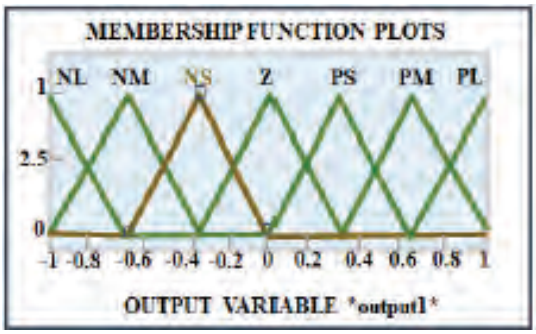

Fig. 10: MF of output variable

Interference Engine: Depending upon these rules the values are evaluated and the fuzzy output is determined.

Defuzzifier: At the end, fuzzy output are converted back into crisp vales for operational use.

This workflow enable the controller to handle unclear and cryptic inputs and produce smooth, adaptive responses. The isolated flyback converter is suitable for galvanic isolations. The power form the WECS is passed through transformer and AC power is converted into DC by the PWM rectifier.

Reduced switch 31-level CHB MLI

The 31 level CHB MLI is illustrated in the fig.10 that comprises of an H-bridge inverter with 8 switches. The input DC voltageV_{in} provides input power for the inverter operations. It generates 31 levels of output voltage, in which the output voltage range range from +15 to -15 volatges including zero voltage level. The each source node corresponds to the specific H-bridge. The 4 polarity generation (T_1,T_2,T_3,T_4) and level generation (S_1,S_2,S_3,S_4)are combined to get a H-bridge. If T_1 and T_2 are activating in positive half cycle, the T_3 and T_4 are in negative half cycles and the voltage attained is zero and generation switches are deactivated.

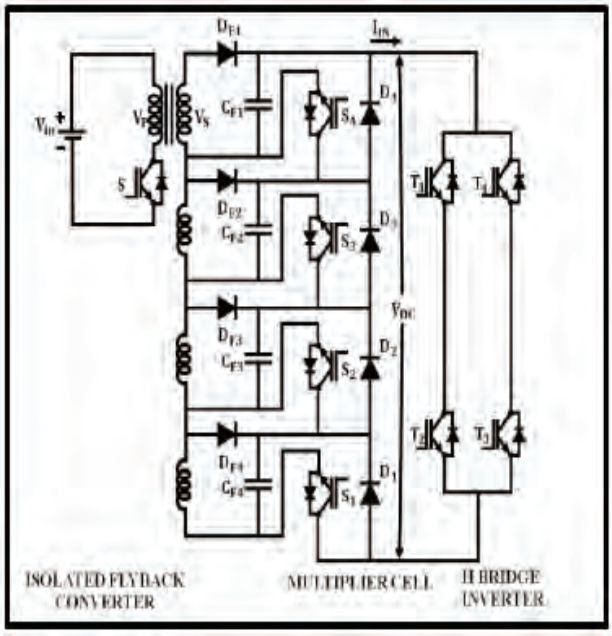

Fig. 11: 31-level CHB MLI

When the S_1 switch is turned ON, the D_2,D_3 and D_4 gets conducted in the positive half cycle. When the S_2 switch is turned ON, the D_1, D_3 and D_4 moves to conduction with transition to mode 2.

The Table.1 displays the appropriate terminal voltages and switching states of 31 level CHB MLI. The switching patterns are modelled to attain individual H-bridge output and regulates the stepped voltage levels. The CHB provides a multi-level AC output waveform. This 31-level inverter, provides 31 distinct voltage levels thus improves the waveform quality and eliminates harmonics.

Table. 1 Switching states and terminal voltages of 31 level Casacaded H-bridge

S_1	S_2	S_3	S_4	Output Voltage
1	1	1	1	$V_{S1}+V_{S2}+V_{S3}+V_{S4}$
0	1	1	1	$V_{S2}+V_{S3}+V_{S4}$
1	0	1	1	$V_{S1}+V_{S2}+V_{S4}$
0	0	1	1	$V_{S2}+V_{S4}$
1	0	0	1	$V_{S1}+V_{S2}+V_{S4}$
0	1	0	1	$V_{S2}+V_{S4}$
1	0	0	1	$V_{S1}+V_{S4}$
0	0	0	1	V_{S4}
1	1	1	0	$V_{S1}+V_{S2}+V_{S3}$
0	1	1	0	$V_{S2}+V_{S3}$
1	0	1	0	$V_{S1}+V_{S3}$
0	0	1	0	V_{S3}
1	1	0	0	$V_{S1}+V_{S2}$
0	1	0	0	V_{S2}
1	0	0	0	V_{S1}
0	0	0	0	0
1	0	0	0	$-V_{S1}$
0	1	0	0	$-V_{S2}$
1	1	0	0	$-(V_{S1}+V_{S2})$
0	0	1	0	$-V_{S3}$
1	0	1	0	$-(V_{S1}+V_{S3})$
0	1	1	0	$-(V_{S2}+V_{S3})$
1	1	1	0	$-(V_{S1}+V_{S2}+V_{S3})$
0	0	0	1	$-V_{S4}$
1	0	0	1	$-(V_{S1}+V_{S4})$
0	1	0	1	$-(V_{S2}+V_{S4})$
1	1	0	1	$-(V_{S1}+V_{S2}+V_{S4})$
0	0	1	1	$-(V_{S3}+V_{S4})$
1	0	1	1	$-(V_{S1}+V_{S3}+V_{S4})$
0	1	1	1	$-(V_{S2}+V_{S3}+V_{S4})$
1	1	1	1	$-(V_{S1}+V_{S2}+V_{S3}+V_{S4})$

RESULTS AND DISCUSSION

The proposed model 31-level CHB MLI efficiency is ensured by the results obtained from the simulations and experimental verifications. A simulation model of the integrated 31-level MLI is designed in MATLAB based on the design parameters given in the below table 2.

Table 2. Parameter Specifications

Specification	Rating
PMSG-Wind System	
No. of Turbines	1
Power	10kw

Voltage	575V
Stator Resistance	0.975Ω
Flux Linkage	0.91Wb
PMSG Inductance	0.01H
Pole Pairs	3
Air Density	1.218kg/m^2
Pitch Angle Beta	2degree
Base Wind Speed	12m/s
DC Link Capacitor	1500μF
DVR	
Switching Frequency	10KHz
Series Voltage Injection	100V
Grid Voltage	415V
Filter Inductance	2.7mH
Filter Capacitance	50μF
Line Resistance	0.1Ω
Line Inductance	0.5mH

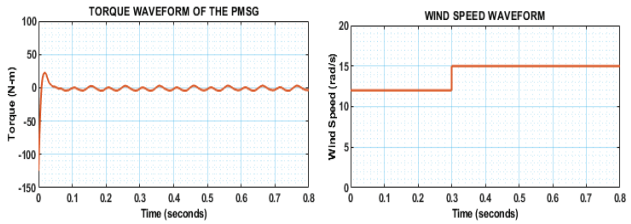

Fig. 12: Torque and speed waveform of PMSG

Fig. 12 displays torque and speed waveforms of a PMSG. The motor speed graph shows initially rises and fluctuates around zero. The torque illustrates a sharp rise followed by a steady value of 15(rad/s).

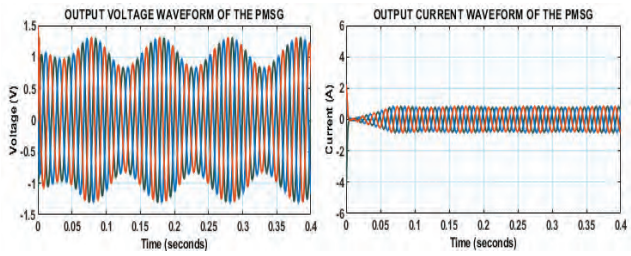

Fig. 13: Output voltage and current waveform of PMSG

Fig.13 illustrates the waveforms of PMSG current and voltage. The voltage is constantly stabilized around 1.25V, while the current is consistently maintained at 1A, thus ensures efficient grid synchronization and power transfer.

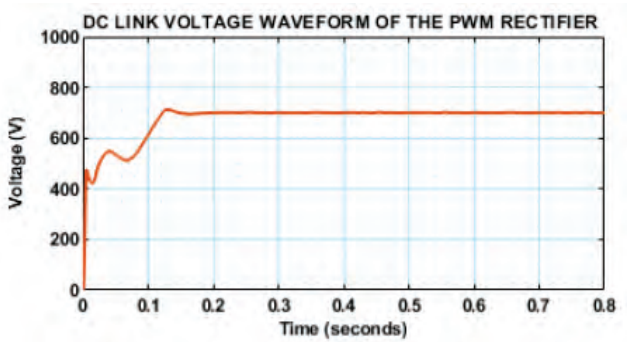

Fig. 14: PWM rectifier DC-link voltage waveform

Fig.14 shows the dc-link voltage waveform of PWM rectifier. The voltage increases initially and stabilizes at the voltage of 700 V after 0.2s.

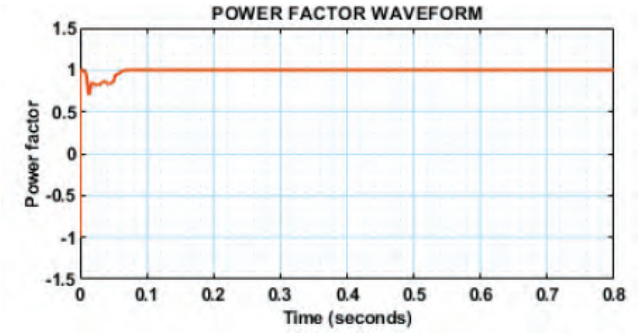

Fig. 15: Power factor waveform

Fig.15 displays power factor waveform of the DVR Fig shows a steady state after 0.1s, indicating that the system stabilizes and maintains a constant power factor over time.

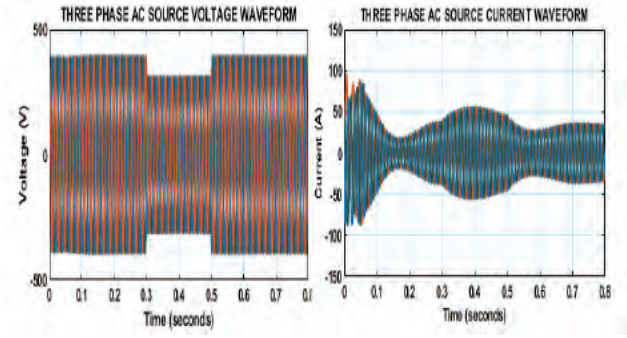

Fig. 16: Three phase AC source voltage and current waveform

Fig.16 represents the waveform of a three-phase AC source voltage and current, where the voltage is 400 V, and the current fluctuates, stabilizing at 40 A after 0.7 s.

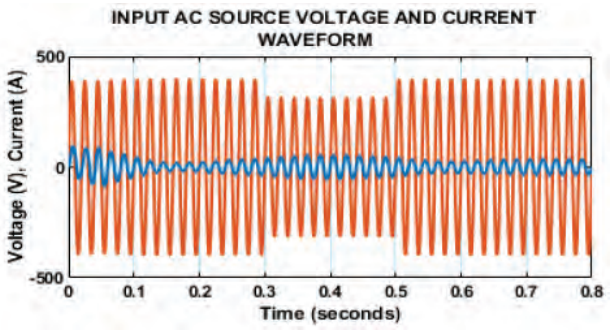

Fig. 17: Three phase AC source voltage and current waveform

Fig.17 shows the waveform of a three-phase AC source, where both voltage and current are maintained at 400 V and 40 A, respectively.

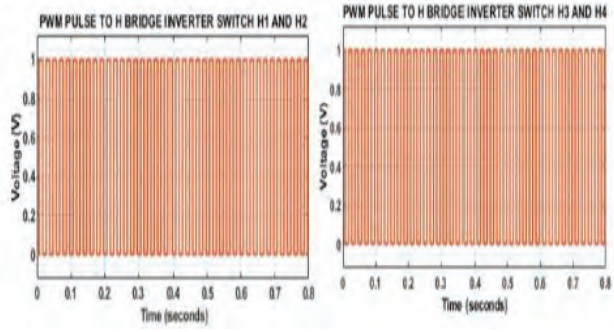

Fig. 18: PWM pulse to H bridge inverter switches

Fig.18 shows an H-bridge inverter with switches H1, H2, H3, and H4, where both pairs of switches maintain a consistent voltage and constant value.

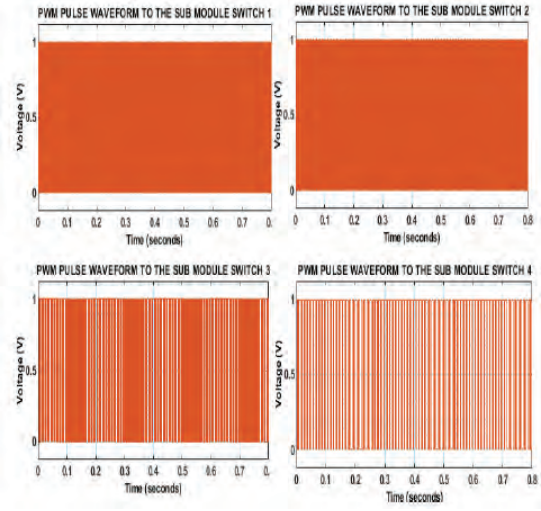

Fig. 19: PWM pulse waveform to sub module switches

Fig. 19 shows waveforms of submodule switches 1, 2, 3, and 4, which maintain a constant voltage level at the beginning of operation.

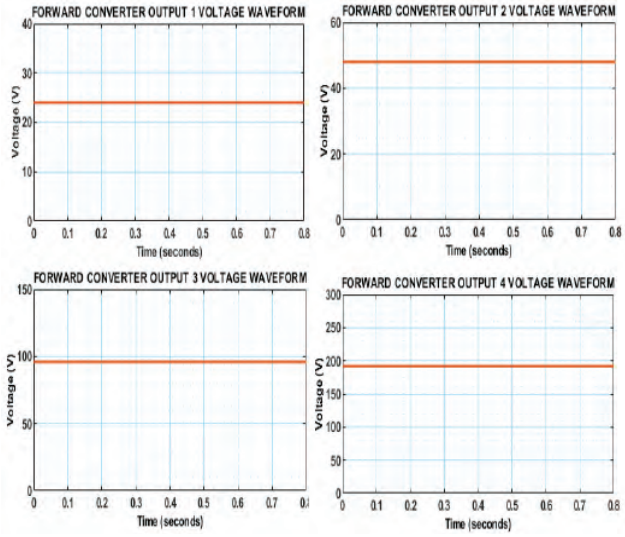

Fig. 20: Forward converter output waveform

Fig.20 shows the waveforms of the forward converter outputs 1, 2, 3, and 4, which maintain stable output voltage levels of 25V, 45V, 95V, and 290V, respectively.

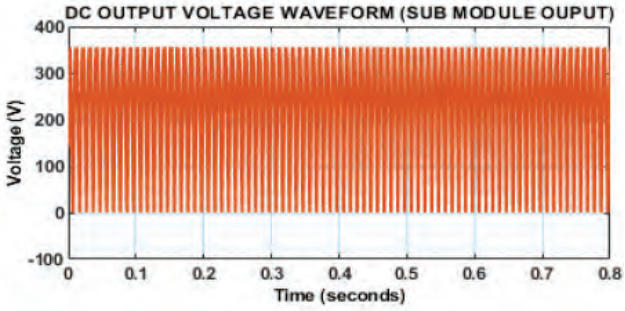

Fig. 21: Sub module output voltage waveform

Fig.21 shows the waveform of the submodule's output voltage, which indicates a stable voltage level of 350 V.

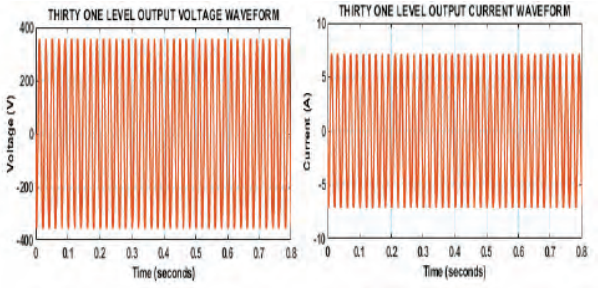

Fig. 22: 31-Level CHB MLI output voltage and current waveforms

Fig.22 illustrates the output voltage and current waveform of 31-level CHB MLI. The voltage waveform shows a stabilized voltage ranges between 350V. The output current is also maintained stable around 7A depicts steady behaviour.

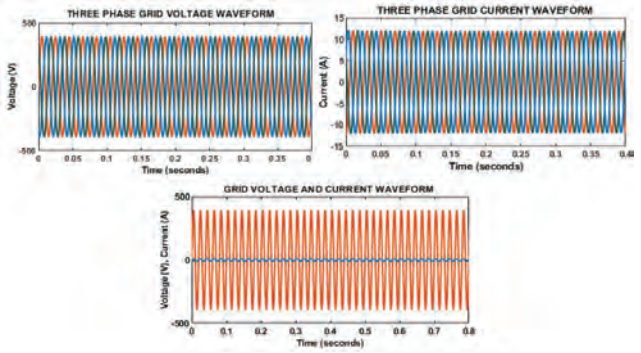

Fig. 23: 3ϕ Grid voltage, current waveform and voltage and current

Fig.23 shows the current, voltage and voltage and current waveform of the 3ϕ grid. The load current waveform stabilizes around 12A and the load voltage of 400V is attained. The current and voltage waveform shows the stable current and voltage levels and ensures overall effectivity of the system.

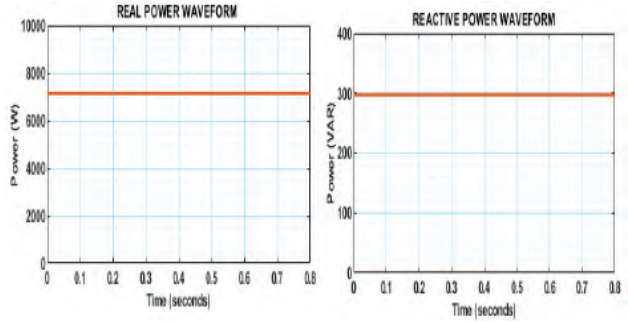

Fig. 24: Real and reactive power waveform

Fig. 24 provides the real and reactive power waveform. The real power waveform attains 7200W while the reactive power of 300VAR is obtained.

Fig. 25 shows the THD waveform of the proposed 31-level CHB-MLI. From the graph, it provides that the proposed technique attains the THD of 2.98%

Fig.26 attains the THD value of 2.98% . From the THD comparison it highlights the proposed 31-level CHB MLI results in low THD than other conventional MLI such as 9-level [14] and 13-level [13] inverters.

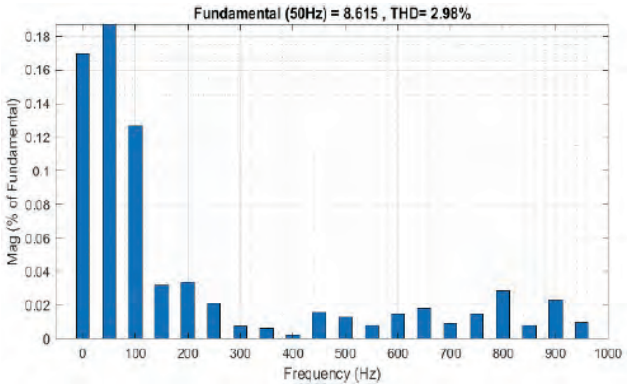

Fig. 25: THD waveform

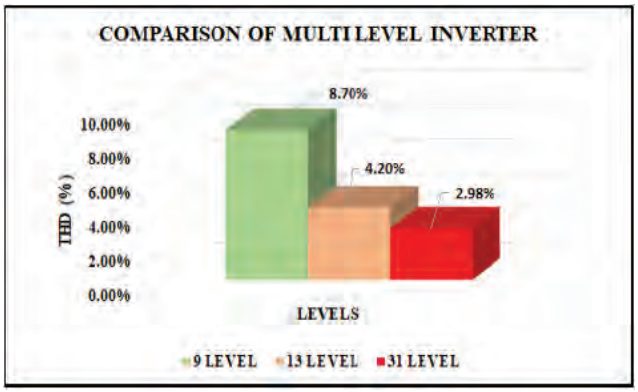

Fig. 26: Comparison of THD waveform

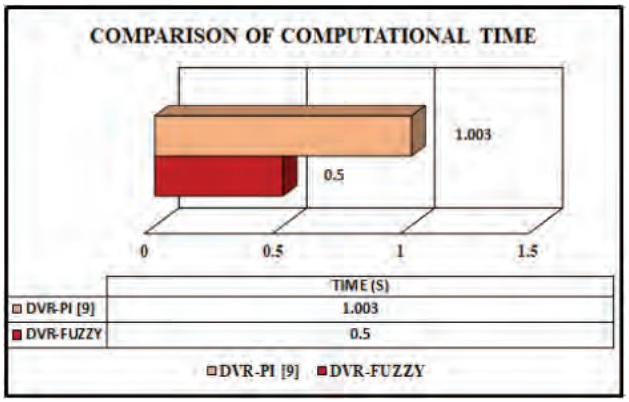

Fig. 27: Comparison of computational time

Fig.27 illustrates the comparison of computational time. It shows that the proposed DVR based fuzzy takes less computational time of 0.5s than the conventional Proportional Integral (PI) [9] controller with 1.003 s.

CONCLUSION

The proposed approach of PMSG-based WECS integrates fuzzy driven DVR enhances LVRT and overall grid sustainability. High power density is generated

from the PMSG. The DVR offers precise control over power quality enhancement issues and controlled by FLC. The 31-level CHB-MLI produces high quality power waveform for effectively transmitting the power to the grid. The proposed approach results in reduced THD value of 2.98%. This shows that the proposed performs under varying load conditions with reduced harmonics. This design is commonly used in high-power applications, enhancing efficiency and reliability.

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Recent Advances in Design and Optimization of Low Noise Amplifiers for Multistandard Receivers

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ABSTRACT

The increasing demand for high-performance, multistandard wireless communication systems, such as 5G, Wi-Fi 6/7, and IoT networks, necessitates low noise amplifiers (LNAs) with improved noise figure (NF), gain, linearity, and power efficiency. This paper provides a comprehensive review of state-of-the-art LNA designs, focusing on six primary topologies: common-source (CS), common-gate (CG), cascode(CC), differential(DF), current-reuse(CR), and reconfigurable(RCF) LNAs. We discuss key performance trade-offs, advanced optimization techniques, and emerging trends in LNA design.

KEYWORDS *: Advanced optimization techniques, Common-source (CS), Low noise amplifiers (LNAs), Power efficiency, etc.*

INTRODUCTION

The growth of wireless multistandard communications is driven by the increased demand for portable and low-cost multistandard devices. In portable devices, the implementation of multistandard systems on a single chip is indispensable to reduce size and cost. Multistandard receivers must be equipped with broadband front-end blocks to cover various standard frequency bands. However, front-end blocks are usually implemented in a narrow band due to the usage of inductors in passive matching networks and high-Q filtering, which cannot be easily scaled down below the 0.18-μm CMOS technology node and affect noise figure [1]. Hence the design of each block must be carefully done since it affects the performance of the overall system and A-to-D converters (ADC) that consume a lot of power due to its high sampling rates. Among front-end blocks, the low noise amplifier (LNA) design is the most critical because it is the first stage of the receiver that amplifies very weak input signals coming from an antenna as shown in Figure1. Besides amplification, the LNA must also match the input signal with the antenna; thus, it must have a good input matching with an almost conjugated transducer gain. Another task of the LNA is to add minimum noise to the amplified signal; therefore, it must have a good noise figure (NF). At the same time, the LNA must have good linearity to avoid degradation of the amplified signal since input signals are usually contaminated with unwanted high power signals, such as those coming from adjacent channels.

There are always trade-offs between NF, gain, power, and linearity. Process variations and temperature

stability in semiconductor technologies is also very important to have the targeted design. The main challenges lie in adaptability to multiple frequency bands. Lowering NF (via inductive degeneration or current reuse) often increases power dissipation. Advanced biasing techniques, such as subthreshold operation in CMOS, mitigate this trade-off. High IIP3 requires larger transistor sizes, which degrade gain and bandwidth. Derivative superposition (DS) and noise-canceling techniques resolve this by balancing nonlinearity cancellation and gain enhancement. FinFET and FD-SOI technologies reduce threshold voltage variability, but mmWave designs still face parasitics (e.g., gate resistance R_g) that degrade NF. Statistical modeling tools like Monte Carlo simulations are critical. Cryogenic LNAs for quantum computing (e.g., 4K operation) require wide-temperature BiCMOS processes to maintain gain flatness.

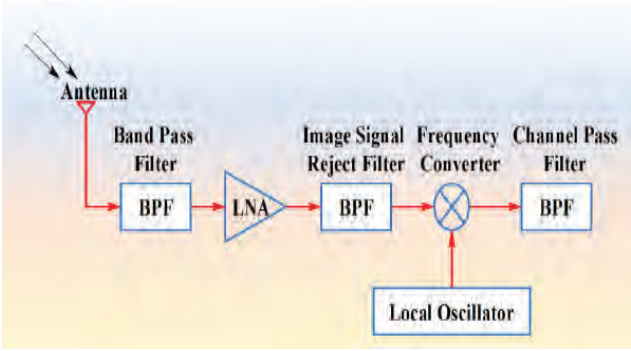

Fig. 1 Receiver Architecture

To address these challenges, three transformative optimization strategies have emerged: (i)Machine Learning (ML)-Based Optimization: Neural Networks (NNs) predict optimal transistor sizing (W/L) and biasing (V_GS) using datasets from SPICE simulations and Genetic Algorithms (GAs) automate topology selection (e.g., cascode vs. differential) by evaluating Pareto-optimal fronts for NF, gain, and power. (ii) Adaptive Biasing: Body Biasing: Dynamically adjusts MOSFET threshold voltage (V_th) to optimize noise/power trade-offs and Current Steering: Reallocates bias current between amplifier stages based on input signal strength.(iii)Non-Foster Matching Networks: Negative impedance converters (NICs) enable broadband input matching (e.g., 2–18 GHz) by canceling parasitic capacitances, overcoming the Bode-Fano limit [39].

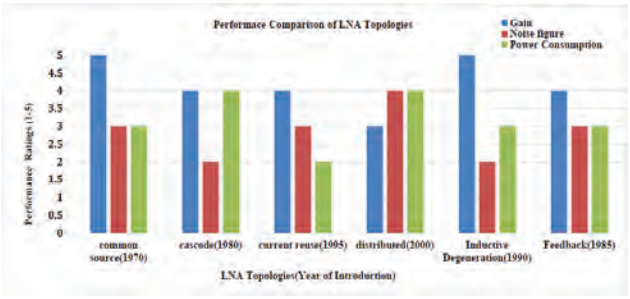

Fig. 2 Performance Comparison of LNA Topologies Over Time [37][38]

REVIEW OF RELATED LITERATURE

The Figure 3 shows the relationship between input and output power in a communication system, which is especially relevant for amplifiers like low-noise amplifiers (LNAs). On the x-axis, you'll find the input power (Pin), while the y-axis represents the output power (Pout). This chart highlights several key areas and points that are important for understanding how amplifiers perform. First up is the Noise Floor. This is basically the baseline output power when there's no input signal, reflecting the internal noise generated by the system. Then we have the Minimum Detectable Signal (MDS), which is the smallest input signal that can be amplified above that noise floor. This measure is crucial for determining how sensitive the amplifier is. Next, we enter the Linear Region. Here, the output power increases steadily with the input power, and the amplifier's gain stays consistent. Moving on, we encounter the 1 dB Compression Point (P1dB). This point marks the input power level where the output power starts to deviate by 1 dB from what you'd expect in an ideal linear gain scenario. It's the point where compression begins, and the amplifier starts losing its linearity. Lastly, there's the Burn-Out Region (BOR). Beyond the compression point, the amplifier hits saturation, meaning that the output power stops increasing significantly with more input power. This area can lead to distortion or even damage to the system. Overall, this illustration is essential for evaluating how effective amplifiers are, pinpointing their operational limits, and making sure they function optimally in applications like wireless communication systems.

CMOS Technology offers low cost, high integration with digital circuits, and scalability to sub-10 nm nodes

but limited f_{max} (~300 GHz in 7 nm FinFET) and higher noise at mm Wave frequencies. Recent Advances shows that FinFETs enhanced transconductance (g_m) due to 3D gate structures. The transconductance model is:

$$g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{th}) \quad (1)$$

where μ_n = electron mobility, C_{ox} = oxide capacitance, and V_{th} = threshold voltage.

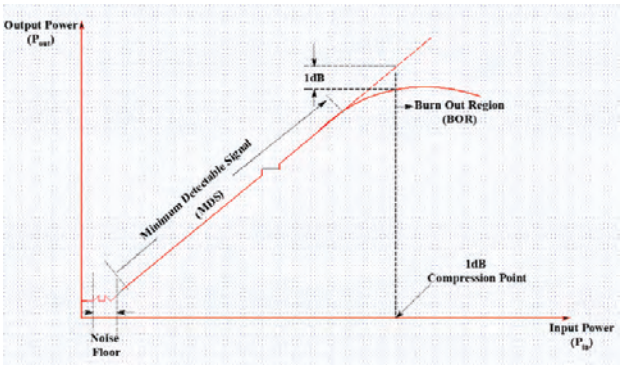

Fig. 3 General consideration for designing a LNA

FD-SOI (Fully Depleted Silicon-on-Insulator) reduces parasitic capacitance, enabling LNAs with NF < 1 dB at 28 GHz (e.g., 22 nm FD-SOI for 5G). SiGe Technology offers high f_T/f_{max} (up to 500 GHz), excellent noise performance (NF < 0.5 dB at 10 GHz) for 5G FR2, satellite communication. IBM's 90 nm SiGe BiCMOS LNAs achieve 18 dB gain and 1.2 dB NF at 140 GHz. Gallium Arsenide (GaAs) offers low noise (NF < 1 dB at 6 GHz) but limited power handling. It is used in Wi-Fi 6/7 LNAs for consumer electronics whereas Gallium Nitride (GaN) offers high power density and thermal stability, ideal for military and mmWave 5G. As presented in [40] GaN LNAs with >30 dB gain and 2 dB NF at 28 GHz InP Technology offers ultra-high f_T (>1 THz), low phase noise for THz imaging, 6G research. In 2022 at NASA, InP HEMT LNAs demonstrate 12 dB gain at 300 GHz.

Table 1 Technology Comparison

Parameter	CMOS [31]	SiGe [32]	GaAs [33]	GaN [34]	InP [35]
NF (6 GHz)	1.5 dB	0.8 dB	0.7 dB	2.0 dB	1.0 dB
Power Handling	Low	Medium	Medium	High	Medium
Cost[36]	Low	Medium	High	High	Very High

Common-Source (CS) LNA [41] operates on single transistor with inductive degeneration for noise matching. Input impedance with inductive degeneration (L_s) is governed by (2)

$$Z_{in} = \frac{1}{j\omega C_{gs}} + j\omega L_s + \frac{g_m L_s}{C_{gs}} \quad (2)$$

where C_{gs} = gate-source capacitance, g_m = transconductance.

It offers high gain (>15 dB) and design is simple but has limited bandwidth (BW < 20% of center frequency). Recent work on a 2.4 GHz CS LNA in 28 nm CMOS achieved 1.3 dB NF and 18 dB gain.

Common-Gate (CG) LNA [42] has an input signal applied to the source terminal for broadband matching and input matching is governed by (3)

$$Z_{in} = \frac{1}{g_m} + j\omega C_{gs} \quad (3)$$

It offers wideband operation (e.g., 3–10 GHz) and inherent stability but offers lower gain (~10 dB) compared to CS. Recent work on 65 nm CMOS CG LNA achieved 2.8–10.5 GHz BW with 2.1 dB NF.

Cascode (CC) LNA [43] combines CS and CG stages for high gain and isolation. Voltage gain is governed by (4)

$$A_v = -g_{m1}(r_{o1} \parallel r_{o2}) \quad (4)$$

where r_{o1}, r_{o2} = output resistances of CS and CG transistors.

It offers improved reverse isolation (>30 dB) and wide bandwidth of operation. Recent work on a 28 nm FinFET cascode LNA achieved 22 dB gain and 1.1 dB NF at 28 GHz.

Differential (DF) LNA [44] uses two symmetric CS/CG stages for noise cancellation. Its differential Gain is governed by (5)

$$A_{v,diff} = g_m(R_D \parallel r_o) \quad (5)$$

where R_D = load resistor, r_o = transistor output resistance.

It offers high linearity (IIP3 > 0 dBm) and common-mode noise rejection. Recent work on a 14 nm differential LNA for Wi-Fi 6E achieved 1.5 dB NF and 25 dB gain.

Current-Reuse(CR) LNA [45] shares bias current between stacked stages for power efficiency. Gain is governed by (6)

$$G = \frac{n g_m Z_0}{2} \quad (6)$$

where n = current reuse factor, Z_0 = load impedance.

It offers 50% lower power consumption than conventional LNAs. Recent work on a 40 nm current-reuse LNA achieved 0.8 mW power and 14 dB gain at 2.4 GHz.

Reconfigurable (RCF) LNA employs tunable components (varactors, switches) for multiband operation. Varactor Capacitance is governed by (7)

$$C_{var} = \frac{C_0}{1+\frac{V_R}{V_0}} \quad (7)$$

where C_0 = zero-bias capacitance, V_R = reverse bias voltage.

It covers 1–6 GHz (e.g., 5G/Wi-Fi/IoT) with adaptive matching. Recent work on a 65 nm reconfigurable LNA using RF-MEMS switches achieved 1.4 dB NF across 1–6 GHz[46].

Table 2 Topology Comparison

Topology	Gain	NF	Bandwidth	Power	Application
CS[28]	High	Low	Low	Medium	Narrowband 5G/Wi-Fi
CG[29]	Medium	Medium	Wide	Low	UWB, IoT
CC[25]	High	Low	Low	High	mmWave 5G
DF[30]	High	Low	Low	High	High-linearity systems
CR[27]	Medium	Medium	Low	Ultra-Low	IoT/Wearables
RCF[26]	Variable	Low	Ultra-Wide	Medium	Multistandard receivers

Recent studies on the design and optimization of LNAs for multi-standard receivers have also been presented. For CMOS LNAs, the geometric sizes of the amplifiers are either used as design variables or only the bias current is used as a design variable and the geometric sizes are fixed according to a certain standard. For multi-standard receiver applications, beside designing different LNAs for different standards, it is also possible to combine different standards into one LNA by using multi-band or wideband techniques [2]. Multi-band LNAs have two operating frequencies which correspond to two different standards. Wideband LNAs have a single input matching network which provides impedance matching over a very wide bandwidth.

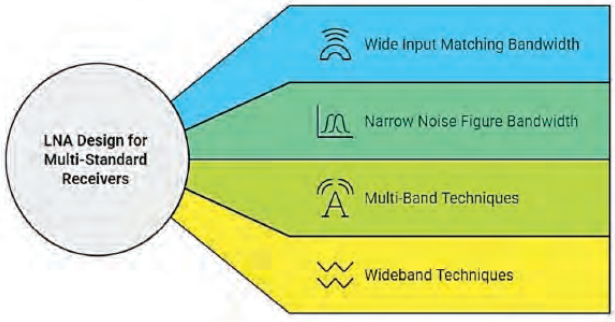

Fig. 4 Key Design Considerations for LNAs in Multi-Standard Receivers

DESIGN AND OPTIMIZATION OF LNA

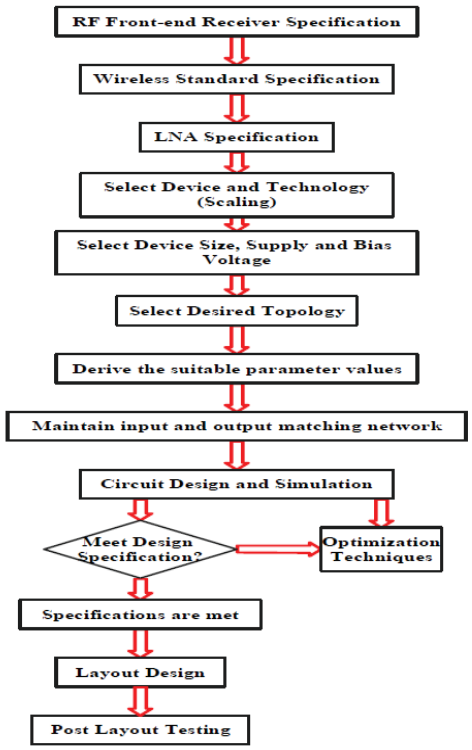

Fig. 5 Design Flowchart for Rf Front-End Receiver and LNS Development [56][57]

The design of low-noise amplifiers (LNAs) for multistandard receivers hinges on optimizing interrelated performance metrics derived from fundamental circuit theory. The noise factor (F_{total}), as defined by Friis formula, quantifies the cumulative noise contribution of

cascaded stages. Since the LNA is the first active block, its noise factor (F_1) and gain (G_1) dominate the system's overall noise performance, necessitating ultra-low F_1 and high G_1 to suppress subsequent stage noise[47].

$$F_{\text{total}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots \quad (8)$$

Input impedance matching, critical for power transfer and minimal reflection, is achieved through inductive degeneration where

$$Z_{\text{in}} = j\omega L_g + \frac{1}{j\omega C_{gs}} + \omega_T L_s \quad (9)$$

This topology synthesizes a real impedance (50 Ω) at the operating frequency, balancing L_g, C_{gs} (gate-source capacitance), and L_s (source degeneration inductance). Linearity, measured by the third-order intercept point (IIP3), governs the LNA's ability to handle strong interferers without distortion. For cascode LNAs, IIP3 scales with transconductance (g_m) as per (10) but is constrained by nonlinearities from C_{gs} and output conductance (g_{ds}). Designers face a trade-off: higher g_m improves gain and noise figure as given by (11) and (12) respectively [48].

$$\text{IIP3} \propto \sqrt{\frac{2}{3} \cdot \frac{g_m^3}{(g_m + g_{ds})^2 \cdot C_{gs}^2}} \quad (10)$$

$$G = \frac{Z_L}{Z_{in}} \cdot g_m^2 \cdot R_L \quad (11)$$

$$NF = 1 + \frac{4R_s}{Z_0} \cdot \frac{\gamma}{\alpha} \cdot \frac{1}{g_m} \quad (12)$$

$$IIP3 = \frac{4}{3} \cdot \frac{g_m}{I_{DS}} \quad (13)$$

Stability, ensured via the K-factor which is governed by equation 7. It guarantees unconditional operation by suppressing oscillations. Modern multistandard LNAs demand K>1 across all frequencies, often requiring neutralization or resistive damping. Reconfigurable LNAs dynamically adjust g_m, L_g, and L_s to balance NF, gain, and IIP3 across standards, while advanced CMOS processes (e.g., FinFETs) enhance g_m/power ratios. Emerging machine learning frameworks now automate this trade-off analysis, enabling Pareto-optimal designs for 5G, IoT, and beyond[49].

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2\,|S_{12}S_{21}|} \quad (14)$$

Adaptive biasing dynamically adjusts the LNA's operating point based on input signal conditions, enabling optimal power efficiency without degrading noise or linearity[50].

$$I_{\text{bias}} = I_0(1 + \alpha \cdot P_{\text{in}}) \quad (15)$$

where I_0 = quiescent bias current, P_{in} = input power, α = scaling factor.

Low P_{in}: Reduces I_{bias} to save power (e.g., IoT applications) and high P_{in}: Increases I_{bias} to maintain linearity (e.g., 5G uplink). Body Biasing in FD-SOI: Adjusts threshold voltage (V_{th}) to modulate g_m and NF. Recent work on a 22 nm FD-SOI LNA achieved 40% power reduction with adaptive biasing while maintaining NF < 1.5 dB.

Machine learning (ML) accelerates LNA optimization[51] by predicting optimal component values and topologies from simulation datasets. Loss Function for Neural Networks is governed by (16)

$$\mathcal{L} = \sum_{i=1}^{N} \left(\text{NF}_i - \text{NF}_{\text{target}}\right)^2 \quad (16)$$

It minimizes deviation between simulated (NF_i) and target noise figure. A recent case study on a convolutional NN (CNN) to optimize a 28 GHz cascode LNA, achieving 1.2 dB NF and 20 dB gain in 48 hours (vs. 3 weeks for manual design).

Traditional passive matching networks face bandwidth limitations due to the Bode-Fano criterion. Non-Foster circuits and metamaterials overcome these constraints. Transmission Line Matching is governed by (17)

$$Z_{\text{in}} = Z_0 \cdot \frac{Z_L + jZ_0\tan(\beta l)}{Z_0 + jZ_L\tan(\beta l)} \quad (17)$$

where Z_0 = characteristic impedance, β = phase constant, l = line length.

Non-Foster Circuits use negative impedance converters (NICs) to cancel parasitic capacitances, enabling broadband matching (e.g., 2–18 GHz).Recent work on a GaAs-based LNA with NIC achieved 1.8 dB NF over 2–12 GHz and metamaterials are engineered structures (e.g., split-ring resonators) provide compact, tunable impedance matching. Recent work on a 5G LNA using metamaterial stubs achieved 1.5 dB NF at 28 GHz with 30% size reduction [52].

Table 3 Comparative Analysis of Optimization Techniques

Technique	Key Benefit	Limitation	Application
Adaptive Biasing[50]	30–50% power savings	Limited to moderate P_in ranges	IoT, 5G handsets
Machine Learning[51]	10x faster design convergence	Requires large training datasets	mmWave LNAs
Non-Foster Matching[52]	5x bandwidth enhancement	Stability challenges	Military radar, SDR

Hybrid ML-Physical Models can combine neural networks with analytical equations for robust optimization. Quantum-Inspired Algorithms provides leverage to quantum computing to solve multi-objective LNA optimization whereas 3D-Integrated Matching Networks use through-silicon vias (TSVs) for low-loss, wideband matching in 3D ICs.

RESULTS AND CHALLENGES FOR MULTISTANDARD LOW NOISE AMPLIFIERS (LNAS)

5G mm-Wave LNAs operating at 28 GHz face unique challenges due to high-frequency parasitics, atmospheric attenuation, and stringent noise requirements (NF < 2 dB). At these frequencies, impedance matching, transistor gain roll-off, and thermal noise become critical. Here, cascode configurations with inductive source degeneration are favored for balancing gain, stability, and noise matching. Neutralization techniques mitigate parasitic capacitance to enhance bandwidth. Advanced CMOS nodes (22 nm FD-SOI, 28 nm bulk) and GaAs are common due to their high f_t/f_{max} and low-loss interconnects [53].

Optimization Strategies like Noise Reduction which minimize gate resistance via multi-finger transistors and optimize bias for minimum NF. Tuning matching networks for maximum power transfer while avoiding stability issues (Rollett's K-factor > 1) will aid in gain enhancement. Moderate current density (2–3 mA) improves IIP3 without excessive power consumption which results in improved linearity. Performance is examined for Gain: 15 dB, NF: 1.8 dB, IIP3: –5 dBm DC Power (P_{DC}): 10 mW [54]. Figure of Merit (FoM) is governed by (18).

$$FOM = \frac{15\,(\text{linear G} = 31.6) \times 0.316\,\text{mW (IIP3)}}{1.51\,(\text{linear NF}) \times 10\,\text{mW}} \approx 0.66 \quad (18)$$

For 5G coexistence with sub-6 GHz bands, switchable matching networks or dual-path LNAs are used to preserve mm-Wave performance while avoiding interference. This will result in multistandard integration[55].

The challenge lies in designing LNAs that can adapt to different wireless standards while maintaining performance, especially in terms of noise figure, gain, and matching networks. This work focuses on the current trends in LNA design for multistandard receivers, including demand for beyond-3G flexibility, tunability, and reconfigurability in small technology nodes. Low noise amplifiers (LNA) designs topologies for multistandard receivers. Multistandard devices are becoming ubiquitous as wireless technology pervades everyday life. A fixed wireless receiver for multiple standards is inefficient and adds cost and space. On the other hand, a fully multistandard RF front-end architecture is complex due to the wide range of frequencies, channel bandwidths, and other design trade-offs it must handle across standards. The simplest alternative is a combination of fixed blocks and variable ones. In this approach, the LNA is designed to handle different standards by varying certain dimensions without altering its topology. Such a device would need to implement a digital control method to select between different fixed passive components or switches with different finger numbers in active loads. This latter alternative is often inadequate as it sacrifices performance for flexibility [1].

Table 4 Performance Comparison of Semiconductor Technologies for Optimized LNA Design iin Multistandard Receivers

Material/ Technology	Noise Figure(NF) (dB)	Gain (dB)	Power Consumption (mW)	Bandwidth (GHz)	5G FoM	6G FoM	Potential Benefits	Potential Drawbacks
SiGe (Silicon-Germanium) [13][24]	0.8 - 1.2	20 - 30	10-50	02-10	3.0 - 6.0	3.5 - 7.0	- Less Cost. - Easy to Manufacture.	- Higher NF than III-V compounds. - Poor o/p at higher frequencies.
GaAs (Gallium Arsenide) [14][15]	0.5 - 1.0	15 - 25	05-30	01-06	4.0 - 7.5	4.5 - 8.5	- Low NF and high gain. - Excellent for high-frequency applications.	- Higher cost than SiGe and CMOS. - Requires high-quality substrates.
InP (Indium Phosphide) [16][17]	0.3 - 0.7	20 - 35	05-40	01-10	5.0 - 9.0	6.0 - 10.0	- Best NF for high-frequency - Suitable for extremely high-speed applications (6G).	- Costly material. - Complex fabrication process.
CMOS (Complementary Metal-Oxide-Semiconductor) [18][19]	1.0 - 3.0	10-20	01-10	01-05	1.5 - 3.5	2.0 - 4.0	- Low power consumption, ideal for mobile devices. - low cost.	- Higher NF - Limited performance for high-frequency applications.
AlGaN/GaN (Aluminum Gallium Nitride / Gallium Nitride)[20][21]	0.8 - 2.0	20 - 40	10-50	01-06	3.5 - 6.0	4.0 - 7.5	- Excellent linearity and high power handling. - Suitable for high-frequency, high-power applications.	- Higher cost - Power consumption can be high.
III-V (InAs, InSb, etc.)[22][23]	0.3 - 0.9	15 - 30	02-30	01-08	4.5 - 8.0	5.5 - 9.5	- Extremely low noise performance. - High gain and power efficiency.	- Costly material. - Difficult to integrate

CONCLUSION

Although significant progress has been made in the design of LNAs, there are still challenges and issues that need to be addressed for mass deployment of multi-standard receivers. In some cases, the demands of a new standard may compromise the performance of existing standards. Currently, many wireless applications are moving towards the ultra-wideband frequency domain, which will impose even more stringent design constraints on LNA topology flexibility. In addition, new technologies will need to be explored to meet the stringent performance demands of LTE systems. Issues surrounding harmonics, biological safety, and interference have also yet to be satisfactorily addressed. Nevertheless, there are opportunities for research to address some of these issues. Future standards are likely to be modified to take advantage of cognitive radio techniques. As such, the LNA may need to detect and adapt to changing environments. Integration of the LNA with other components is also an ongoing area of research, particularly in reducing noise figure through the integration of RF MEMS devices [4]. Finally, addressing some of the health concerns currently being investigated in part through engineering solutions will also open up new avenues for research [8].

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Identification and Model Predictive Control of Thermo Fluid Boiler

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ABSTRACT

The use of engines and machinery in all fields necessitates the use of high-quality lubricating oil. The dynamics of the thermic fluid heater employed in the blending process determine the quality of the lubricating oil. To obtain the needed lube oil quality, the temperature of blending fluids, such as base oil and additives, must be added at the desired level. The first principle model used in this work is used to simulate a thermal fluid heater. MATLAB is then used to create the experimental model using the input-output data. Using various structure models such as Transfer function, Auto-Regressive error with exogenous input (ARX), Auto-Regressive with Moving Average error with exogenous input (ARMAX) and numerical algorithms for subspace state space system(N4SID) for Thermo fluid heater dynamics is identified from the input-output data. These models have been identified and are reliable. The model is to be used for further process control studies. Identified models from the input and output are validated using the first principle model. PID and DMC controllers are used to analyse the performance of the best-identified models.

KEYWORDS *: ARMAX, ARX, DMC, N4SID, PID, Thermic fluid heater.*

INTRODUCTION

New machines with many moving surfaces are created to suit customers' ever-increasing demand in all areas, such as transportation, power plants, agriculture, food processing, etc. The performance of any moving system depends on the quality of the lubricating oil. This lubrication oil decreases friction between moving surfaces, reducing corrosion and heat generation from moving surfaces and, as a result, increasing machine efficiency. The appropriate additives and viscosity modifier are blended with the essential oil at the desired temperature to make lube oil. The base oil and additives used are determined by the type of lubricating oil being blended. (Engine oil, gear oil, transmission oil, etc.) The temperature of the blending process must also be maintained at the right level in order to create the required properties in the final lubricating oil. Thermodynamic fluid heaters, temperature sensors, and the requisite electronics for automation are utilized for heating and keeping the temperature at the required level (Shufa Yan et al., 2019). It needs the selection of the best thermic fluid heater type and the design of a controller to ensure the quality of the lubricating oil (Mihai Huzmezana et al., 2002).

Model identification is carried out in (Liu Changliang et al., 2004) using MATLAB simulation, but the

parameters of the identified model are using the genetic algorithm. The temperature process is naturally slower, but it is necessary to speed up the control action in many applications. As a result, improved proportional-integral-derivative PID controller designs for temperature control systems were developed (Rames C Panda, 2009; Normey-Rico Julio E and Jose Luis Guzman, 2013). In (Un-Chul Moon and Lee Kwang Y, 2009), a new controller called the dynamic matrix controller (DMC) for boiler-turbine systems is presented, in which many variables are controlled to the desired level. The step response model is used to identify the system. This controller eliminates both overshoots and undershoots.

BLENDING PROCESS

A typical blending system consists of the following sections

The base oil is pumped into the thermic fluid heater, which is heated to the required temperature and returned to the blending vessel for homogenization. Additives are added to the base oil at a temperature necessary to get the desired qualities in the lubrication oil. By adjusting the fuel flow rate to the chamber's burner, the appropriate temperature of the base oil can be achieved. Thermocouples are used to sense the temperature to automate the temperature control procedure. The product is filtered after mixing and then transferred to storage tanks.. Various type of lubricant products necessitates different oil compositions and qualities (Shufa Yan et al., 2019).

Thermic fluid Heater

Thermic fluid heaters, also known as thermal oil heaters, are made up of two concentric coils twisted in a cylindrical shape, as well as a blower and a burner. The temperature of the thermal fluid circulating between the two concentric coils must be brought up to the necessary level. The temperature of the fluid is raised by changing the flow rate of the combustion liquid fuel in a burner at the top of the stack. High-density Rockwool insulation between the two casings prevents burns from unintended contact with the boiler, resulting in minimal losses.

The flame from the burner is directed into the combustion chamber. As a result of the concentric coil being exposed to the flame, the base oil is heated. The chamber is sealed shut by refractory behaviors. As a result, the flame's direction changes, and combustion gases circulate at a high rate within the chamber. As a result, the temperature profile of the base oil improves overtime.

SYSTEM IDENTIFICATION

This input-output data is used for identifying the system using the transfer function model, ARX model, ARMAX model and N4SID model, as described below.

Experimental transfer function model

The transfer function obtained is given below.

$$\frac{T_o}{F_i} = \frac{21.889e^{-9s}}{26.504s+1} \quad (1)$$

The transfer function shows that the system to be modelled as first order plus dead time (FOPDT). It can be used as the reference transfer function to develop and validate the models using ARX, ARMAX and N4SID algorithms.

ARX model

A disturbed linear discrete-time model is typically used to represent process dynamics. The Box-Jenkins (B J) model structure can be considered a particular instance of all linear black-box single input single output model structures. ARX structure is obtained by setting C = 1, D = A in the B J model structure (Wayne Bequette B , 2003) .

Based on the experimental transfer function we can approximate our system as a first order plus dead time model. Therefore, the corresponding ARX model for our system is

$$\frac{Y(p)}{U(p)} = \frac{b_1 p^{-(d+1)}}{1+a_1 p^{-1}} \quad (2)$$

That is the system parameters such as process gain K_p, time constant τ_p and dead time θ, are calculated from a1, b1, d and sampling interval T_s as shown below.

$$K_p = \frac{b_1}{1-a_1}, \quad \tau_p = \frac{-T_s}{\ln(a_1)} \ \& \ \theta = d \times T_s \quad (3)$$

Finally, the transfer function of our system using this ARX model becomes,

$$\frac{T_o}{F_i} = \frac{26e^{-5.6s}}{27.8s+1} \quad (4)$$

ARMAX model

The ARMAX model is more flexible in handling the disturbances than ARX model. That is, when close approximation of the system is not identified using ARX model, then ARMAX algorithm can be applied to reduce further the error between the predicted model output and the actual model output. It is accomplished by modelling the error term in ARX model as a moving average of white noise that results in ARMAX model, as shown below (Karel J. Keesman 2011).

$$K_p = \frac{b_1+c_1}{1-a_1}\ , \tau_p = \frac{-T_s}{\ln(a_1)}\ \&\ \theta = d \times T_s \quad (5)$$

N4SID model

State space representation of a system is also useful technique in analysing the behaviour of the system. N4SID is the powerful numerical algorithm for subspace state space system identification, using which system matrices can be estimated from the input-output data. The state-space model of our Linear- time- invariant system by considering output error approach in discrete domain is given as (Brian Raafiu and Purwadi Agus Darwito, 2019) .

From the input-output data the unknown system matrices are found using MATLAB's function N4SID that is given as A = [-0.04025], B = [-0.8512], C = [1] and D = [0].

DESIGN OF CONTROLLERS

Design of PID Controllers

Traditional PID controllers are the most extensively employed in all industrial control applications. The Ziegler-Nichols method is used to find the tuning parameters of PID controllers.

Design of Dynamic Matric Control

DMC is based on the step response model as (Rake H 1980), and the following procedures must be performed while implementing DMC for any process.

Develops a step response model of length N, based on the time Δt.

Specify the Prediction horizon (P) and control horizon (M).

Specify the weight on the control action.

All calculations assume deviation variable form, so remember to convert to/from physical units

RESULTS AND DISCUSSION

The first section compares the identified model from input-output data to the model developed using the first principal approach. The system's performance was then evaluated using the PID and DMC algorithms.

Validation through comparison of Identified Model

In section 4, the identified model of the thermo boiler is carried out utilizing several model structures such as transfer function, ARX, ARMAX, and N4SID. The first principle model is also determined by using the fundamental principle stated in section 3, which involves the application of physical laws to obtain the model. The system parameters of several model structures are determined. The first principle model thus obtained is given below.

$$\frac{T_o}{F_i} = \frac{22.86e^{-9s}}{25.21s+1} \quad (6)$$

First principle model and all the various structure models are determined in section 4 was shown in table 1.

Table 1: First principle, experimental, ARX, ARMAX and N4SID transfer functions

S.NO.	Identification method	Identified Model	Transfer function Model
(i)	First principle model	$\frac{T_o}{F_i} = \frac{22.86e^{-9s}}{25.21s+1}$	$\frac{T_o}{F_i} = \frac{22.86e^{-9s}}{25.21s+1}$
(ii)	Transfer Function Model	$\frac{T_o}{F_i} = \frac{21.889e^{-9s}}{26.504s+1}$	$\frac{T_o}{F_i} = \frac{21.889e^{-9s}}{26.504s+1}$
(iii)	ARX model	A = -0.03571, B = &C = 0.9353	$\frac{T_o}{F_i} = \frac{26e^{-5.6s}}{27.8s+1}$
(iv)	ARMAX model	A = -0.03586, B = 1, C = 1.033	$\frac{T_o}{F_i} = \frac{28.8e^{-5.6s}}{27.89s+1}$
(v)	N4SID model	A = -0.04025, B = 1, C = 0.85	$\frac{T_o}{F_i} = \frac{21.25e^{-7s}}{25s+1}$

The transfer function model is as close to the parameters of first principle model. So, transfer function model is taken for simulation

PID and DMC controller response

The PID controller algorithm is applied to the system by applying Ziegler Nichols tunning parameters. The PID response of valid identified model and first principle model is shown in figure 1 and time domain specification is shown in table 2.

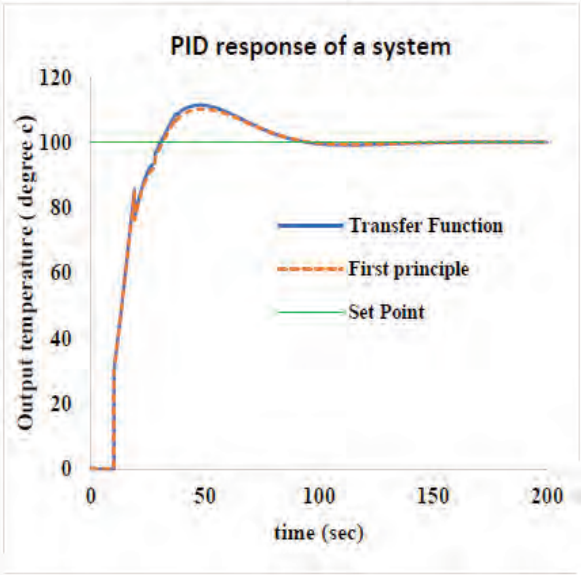

Fig. 1: PID response of identified model and first principle model

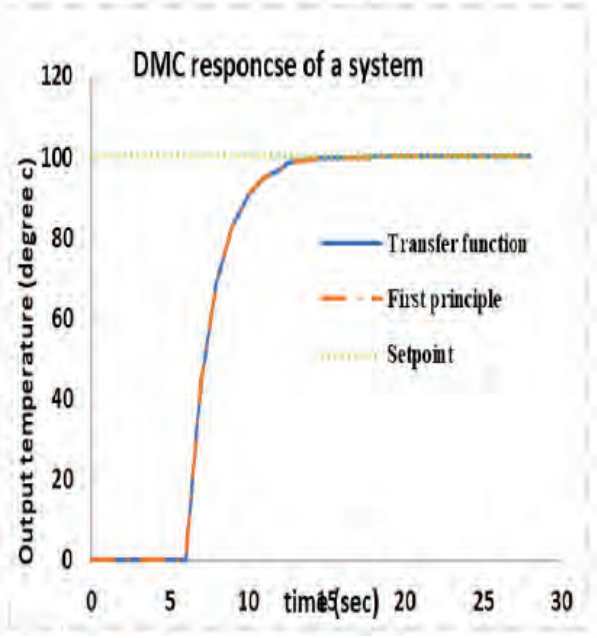

Fig. 2: DMC response of identified model and first principle model

Table 2. Time domain specifications of all models with PID control

Model	Rise time(s)	Peak overshoot (°C)	Settling time(s)
First principle	31.4	5	97
Experimental transfer function	30.4	6	94.5

Performance comparison of PID and DMC controller

When the DMC controller is used, the step response has no overshoot or undershoot, as shown in Figure 2. When a PID controller is used, the dynamic error is increased, and however, when a DMC controller is used, the error is reduced. In addition, compared to a PID controller, the DMC controller has a faster response time (reduced rise time and settling time). It is clear from table 3 comparison of settling time achieved with PID and DMC controllers.

Table 3. Comparison of settling time with PID and DMC controller

Transfer function model	Settling time (s)	
	With PID Controller	With DMC controller
First principle	97	19.5
Experimental	94.5	19.5

CONCLUSION

The problem of maintaining good lubricant oil quality is addressed in this research by managing the temperature of the thermal boiler used in the blending process. The mathematical model of a Thermo boiler is critical.

From the observed open loop input-output data set, the experimental transfer function of the system is computed using MATLAB. The experimental transfer function and the first principle transfer function are very similar. PID and DMC findings were verified; DMC gives a 100% decrease in overshoot and a 5:1 reduction in settling times compared to the PID Controller output. By selecting a DMC controller to manage the temperature of a thermal boiler, the boiler's performance is increased, and the product quality is improved.

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An Integrated Approach to Real Time Anomaly Detection and Physical Layer Secured Routing in Wireless Multi-Hop Networks

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ABSTRACT

Objective: The paper considers a new PLSR algorithm for both the enhancement of security and performance in full-duplex multi-hop wireless networks. Its main goals here include combining the parameters of the physical layer along with advanced routing and security techniques for countering various types of threats in the network while remaining highly efficient. **Method:** The proposed algorithm eliminates the need for having an overall knowledge of the network, which helps in reducing computational complexity as well as the dependency toward network-wide synchronization. The system employs the utilization of sophisticated metrics like the Jaccard Coefficient, Cosine Similarity, and Levenshtein Distance for neighbor validation, attacker identification, and the routing of data. Real time anomaly detection is innovatively implemented within the system using dynamic and adaptive parameter tuning for effective handling of drastic changes in data behaviour. Moreover, the algorithm uses ECC for cryptographic key generation and data encryption, which provides high security with minimal computational requirements. The proposed method avoids reliance on global CSI and employs adaptive strategies to address significant deficiencies in the existing literature. **Results:** Simulation results confirm the effectiveness of the algorithm, showing significant improvements in network security, accuracy of attack detection, and overall system performance. With average packet delivery ratios of 82.14%, the average secrecy capacity was 3.30 bps, and the network attack detection ratio was 100%. These improvements are comparative ones in terms of data delivery efficiency and network security; therefore, the proposed algorithm is a robust, scalable, and efficient solution for future wireless networks

KEYWORDS *: Wireless full duplex nodes, Jaccard coefficient and distance, Cosine similarity and distance, Adaptive filtering, Anomaly detection jamming attack.*

INTRODUCTION

The inclusion of PLS with routing protocols in full-duplex multi-hop wireless networks is an important step towards mitigating the issues associated with the fortification of both the security aspects and the operational capabilities of the network. Security consideration at the physical layer is focused by the innovative techniques introduced by the proposed Physical Layer Secured Routing (PLSR) algorithm for the rigorous enhancement of the robustness of communications over wireless links against malicious interference attacks, including jamming and eavesdropping attacks. This method utilizes well-known metrics, including Cosine Similarity and Jaccard Coefficient, to make routing decisions in a reliable manner while also supporting real-time anomaly detection that can reactively address changes in the network and adversarial attacks. The motivation to integrate PLS with routing stems from the increased vulnerabilities of traditional cryptographic techniques in dynamic resource-constrained environments. Traditional methods are not strong enough to prevent advanced threats, especially for applications like IoT

and VANETs. Information-theoretic security, which is independent of computational powers, makes PLS a better choice than cryptography techniques [1]. In addition, PLSR offers secure key distribution that does not rely on the existence of previously shared keys [2] and improves the detection capability of attackers, thereby decreasing the chance that the adversary may recover keys [3]. Current approaches primarily rely on resource-intensive cryptographic techniques or those that cannot adapt to the real-time dynamic nature of network behaviors. To bridge these gaps , Rami, Ahmad et al (2024) employs an adaptive mechanism for anomaly detection based on OAKF. Due to this mechanism, false positive and negative percentages are dramatically reduced, and up to 95.4% accuracy is found in real-time implementations [4]. More advanced models, like V-GCN, further improve toward anomaly detection. In such improved models, 95% AUC-ROC is found for anomaly detection performance [5].In addition, the algorithm is resource-aware and uses frameworks like Mateen, which picks representative samples for reducing overheads while still allowing adaptability to benign behaviors [6]. This way, physical and cryptographic security to address vulnerabilities in multiple layers and provide a holistic defense against attacks of different types [7][8]. Statistical validation metrics, and also decision trees, random forests, and neural networks in the form of machine learning methods, allow real-time identification of anomalies in network behavior for rapid response to threats [9]. Another algorithm from this class that shows good adaptation to a wide variety of network setups, like smart grids of modern generations and IoT devices, is PLSR. Real-time performance of the model in such environments is tested with advanced models, including LSTM networks for the analysis of time-series data [11]. In combination, these characteristics and efficient resource utilization with a secure architecture make the physical layer security approach provides an innovative solution that is more effective in the context of modern wireless networks.[12].

SECTION-I

Proposed Physical Layer Secured Routing Algorithm (PSLR)

The PSLR algorithm presented here has achieved physical layer security enhancement by employing a comprehensive methodology that integrates a neighbor validation using changed technique, signal strength analysis, and attack detection. This multi-faceted approach effectively enhances the security of the wireless network at the physical layer, providing robust protection against various attacks.

Neighbor Validation

In wireless networks, the physical layer deals with the transmission and reception of signals, and is characterized by signal strength, propagation delay, and distance. Neighbor validation utilizes these physical layer characteristics to ensure that nodes claiming to be within communication range are actually present and behaving consistently with their declared status.

Cross-referencing the signal strength and the distance against the expected values for legitimate nodes can detect discrepancies those are indicating the presence of malicious nodes. If a node claims to be a neighbor but its signal strength is inconsistent with its claimed proximity, or if the similarity in neighbor lists deviates significantly from expected patterns, the node can be flagged as suspicious.

Jaccard Coefficient Calculation

The Jaccard coefficient quantifies the similarity between two sets of neighbors for two nodes i.e. set1 and set2. neighbor list is used to compute Jaccard Coefficient of similar neighbor's nodes. This coefficient ranges from 0 to 1, where 0 indicates no overlap between the sets (i.e. completely different sets) and 1 indicates complete overlap (i.e. identical sets). The coefficient is computed using following formula.

$$\text{Jaccard Coefficient} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|} \quad (1)$$

Where $|A \cap B|$ is the size of the intersection of the two sets that specify number of common elements and $|A|$ is the size of List set1 and $|B|$ is the size of List set 2.

Jaccard Distance Calculation

The Jaccard distance is derived from the Jaccard coefficient and represents the dissimilarity between two sets [9]. It is calculated as follows.

$$\text{Jaccard Distance} = 1 - \text{Jaccard Coefficient} \quad (2)$$

A low Jaccard coefficient i.e. high Jaccard distance, indicates malicious node and implies dynamic corrections to security parameters.

Cosine Similarity Calculation

The Cosine Similarity is useful measure which represents data vectors but needs to know whether they point out the same direction. This in turn helps to determine the similarity of the data patterns between nodes [7]. It is calculated as follows.

$$\text{Cosine Similarity} = \frac{\Sigma A_i \times B_i}{\sqrt{\Sigma A_i^2} \times \sqrt{\Sigma B_i^2}} \quad (3)$$

Here, and represent individual elements of the vectors A and B. Cosine similarity set true/false flags to decide node's behavior is consistent or not consistent with the rest of the network. If Cosine similarity is true, it suggests normal behaviour; if false, it indicates a deviation that indicate malicious activities such as signal jamming, spoofing, or data injection attacks.

Anomaly Detection Using Node Distant Matric

The PLSR algorithm performs neighbor validation by computing Euclidean distance between two nodes (x_1, y_1) and x_2, y_2) in the network and analyze network behavior patterns. It is computed as follows.

$$d = \sqrt{(x_2 - x_1)^2 + (Y_2 - Y_1)^2} \quad (4)$$

In eq.4, d is the Euclidean distance between the two points which helps 'DL_function' to identify problems at a network level by examining distance variation. The function calculates the costs of substitution, insertion, deletion, and transposition for all neighboring nodes to find the minimum distance metric 'min_d', which flag harmful patterns. The minimal distance classifies each node as normal or suspicious. The 'DL_result array' stores the computed results[13].

Adaptive Filtering for the Identification of Anomalies

The PLSR algorithm facilitates the 'Automatic Lag Adjustment Method' for anomaly detection. The algorithm makes the system more sensitive to existing anomalies while preventing redundant positive results by dynamically recomputing the lag based on past and present data deviations. The baseline is computed using statistical metrics 'mean μ' and the 'standard deviation σ' of past data. [14][15].

Sensing Jamming Attacks

The most important function 'recvHello' detects jamming attacks by checking the occurrence of duplicated "Hello" messages from the same node with identical sequence numbers. If this duplication surpasses a threshold, then the node may be identified as a malicious node and appropriate countermeasures should be invoked against such a node. [10][11].

Encryption of Data Packets

Cryptography plays vital role in the proposed algorithm which secures the communication in the wireless networks. The PLSR Algorithm has employed Elliptic curve cryptography (ECC) . It generates public- private key pair, distinct for each node in the network. To generate the keys, the 'generate_key() function' uses the NIST B-163 elliptic curve. It is obtained using eq. 5.

$$y^2 + xy = x^3 + ax^2 + b \ (mod\ p) \quad (5)$$

In equation 4, a and b are curve constants, p is a prime number denoting the finite field.

Each node (r,s) uses the Elliptic Curve Digital Signature Algorithm (ECDSA) to authenticate, to ensure integrity and security as RSA but with the use of smaller key sizes such as 163-bit ECC keys compared to 1024-bit keys of RSA.

$$r = (kG)_x \ (mod\ n), \quad (6)$$

$$s = k^{-1}\left(H_{(m)} + sr\right) \ (mod\ n) \quad (7)$$

In above equations, key k is a random number, n is the base point G order, and H(m) is the hash message. Other nodes then validate the signature to authenticate the sender and message integrity.

SECTION-II

RESULTS AND DISCUSSIONS

Simulation Environment

The PLSR algorithm is simulated in NS2 platform. Two reference physical layer security enhancement schemes for full duplex nodes have been simulated. One scheme

selects relay with source-destination and global CSI The Multi-Relay Node Management (MRNM)[13] has considered and second scheme Bi-Level Security (BLSF) [14] framework has used a composite signal approach

with untrusted relay nodes. This simulation was chosen because it allows for the comparison of security in full-duplex wireless networks. Management of Multi-Relay Nodes (MRNM)[13] Using the source-destination pairs and global Channel State Information, several relay nodes in this approach have managed to provide network

security; hence, this approach is the benchmark. Bi-Level Security Framework [14] BLSF was selected for its innovative composite signal technique for untrusted relay nodesComparing

PLSR with BLSF shows how the proposed algorithm secures communication in untrusted relay nodes, proving its robustness in modern network conditions. The simulation uses MAC 802.11 along with the 'TwoRayGround' channel propagation model for a period of 200 seconds. It uses Constant Bit Rate (CBR) data generation and 100-byte packet size distributed over 50 nodes to create a stable comparative environment. Fig. 1 is compared with the reference methodologies presented above to estimate PLSR's security resilience, efficiency, and attack detection capabilities.The analysis is carried out on the basis of the parameters associated with Security Performance and Network Performance. Critical metrics include secrecy capacity, probability of non-zero secrecy capacity (PNZSC), packet delivery ratio (PDR), throughput, CPU usage by users,memory consumption, and latency. Fig 2 shows 3.11 bps as the highest secrecy capacity and maintained it at 3.45 bps during overall simulation time. Ability to preserve secrecy despite presence of attackers. This suggests that PLSR strikes a balance between security and performance .Fig 1. Algorithmic representation of Proposed PLSR Algorithm.

Fig. 3 shows the relationship between attacker and PNZSC.It hows the probability of positive amount of secret information that may be communicated consistently over a communication channel in presence of an eavesdropper. A high PNZSC suggests that the channel can send certain amount of secret information more securely and the network security is enhanced while sending the data. Thus, the PLSR has improved overall security as compared to other techniques.

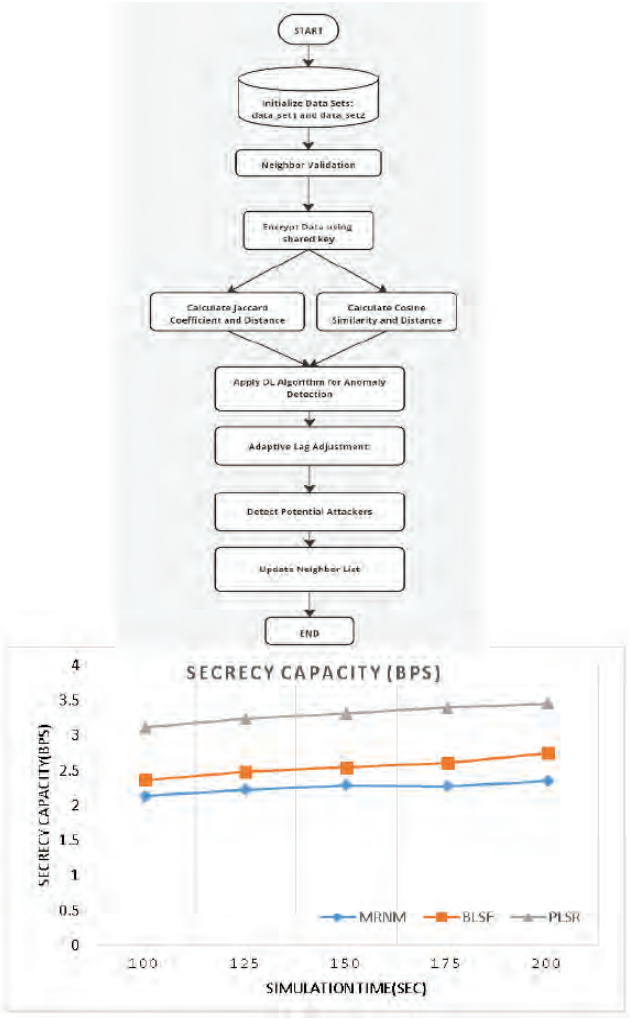

Fig. : 2 Secrecy Capacity

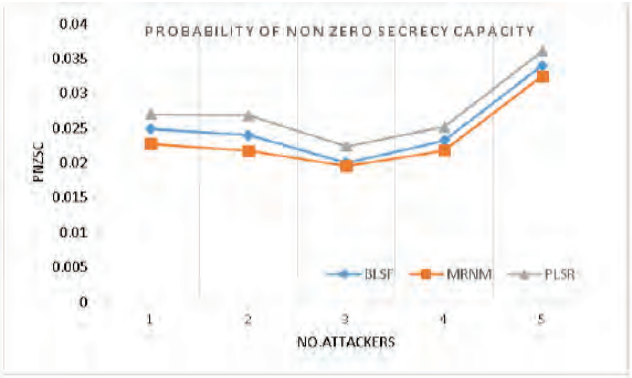

Fig. 3 Probability of Non-Zero Secrecy Capacity

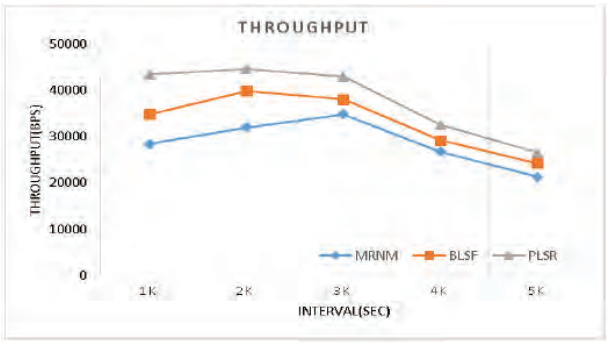

Fig. 4 Throughput

Figures 4, 5, 6, depicts Throughput, Packet Delivery Ratio & Delay as comprehensive network performance measures.

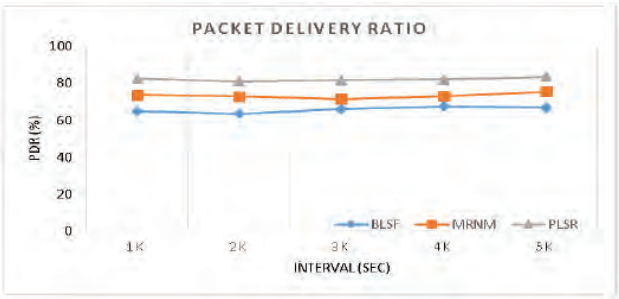

Fig. 5. Packet Delivery Ratio

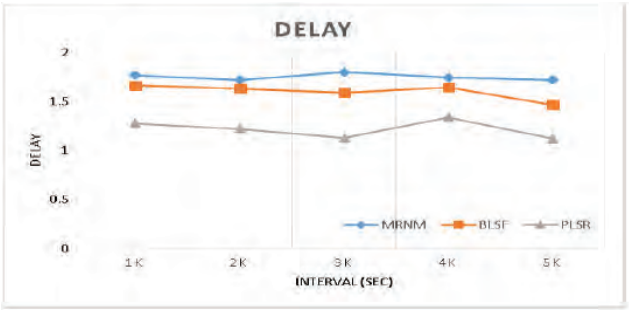

Fig. 6. Delay

The metrics indicate the favorable network transmission condition as security performance of the network is improved by employing the PLSR method. Figure 5 illustrates that the PLSR has achieved an average packet delivery ratio of 82.14%.

Fig 7 shows the percentage of CPU instructions executed in user space. In NS2 simulation, the CPU usage (%) shows the percentage of CPU time used by tasks or user-driven processes. Fig 7 shows that BLSF requires the highest amount of computation, whereas PLSR provides superior memory usage. PLSR is the most memory-efficient with the lowest memory usage (395,008 kB). Its CPU usage at 3.3% of user space is much higher than MRNM and is still relatively moderate. Fig 8 shows plot of load average vs. time interval.

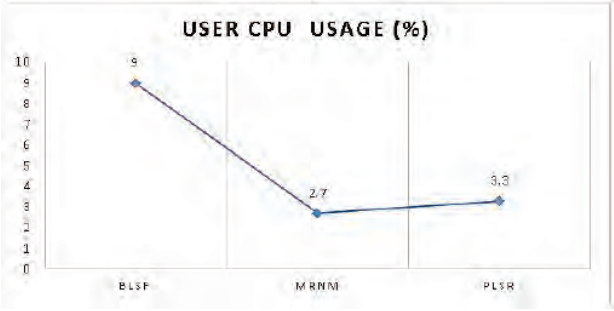

Fig. 7. User CPU Usage (%)

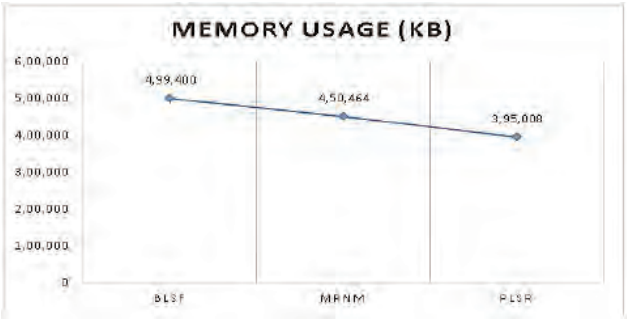

Fig. 8. Memory Usage (kb)

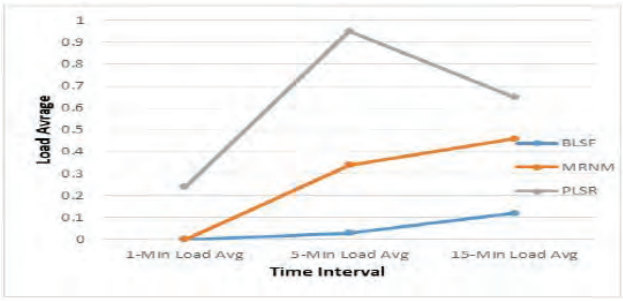

Fig. 9. Load Average

The Load average serves as a metric for CPU performance, reflecting the average quantity of processes awaiting execution and thereby signifying the system's effectiveness in managing its existing workload. The load average associated with PLSR is the most raised among the three metrics assessed, implying that the system's demand throughout the simulation period was correspondingly greater but such a high load average is

not followed by noticeable degradation in performance in term of delays as fig: 6 shows or dropped packets then it is an indication that the algorithm could really work well even under heavy workloads.

SECTION-III

CONCLUSION AND FUTURE SCOPE

The proposed PLSR algorithm presents an innovative and secure framework tailored for full-duplex wireless communication systems, addressing some of the key constraints of the current approaches by combining sophisticated physical layer security techniques with effective routing protocols. Unlike the traditional methodologies that rely on global CSI or fixed thresholds, PLSR relies on adaptive approaches such as neighbor validation with the Jaccard Coefficient and Cosine Similarity. Real-time analysis of signal and noise is considered in order to identify and effectively counter threats of jamming and eavesdropping. Applying ECC, the algorithm is designed to ensure a safe key exchange with a minimum amount of computational overhead, while providing increments both in the security and network performance: packet delivery ratio is at 82.14%, average secrecy capacity at 3.30 bps, and 100% attack detection. However, latency in ultra-dense networks will be introduced, and the performance can be optimized in those environments that are significantly resource-constrained. The promising applications of PLSR towards 5G, IoT, and smart grids lie in areas where scaling and dynamic adaptation are major concerns.

Future research recommendations: integration of more advanced machine learning models for further improvement in anomaly detection, the compatibility of this scheme with ultra-dense network scenarios, and energy consumption problems in IoT devices. There are still some open questions concerning its robustness against coordinated multi-layer attacks, adaptability to evolving network architectures, and security-throughput trade-offs in very dynamic scenarios. These domains present potential areas for further improvement, thus ensuring the effectiveness of PLSR as a unified technique to secure communication in future wireless networks.

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Effects of FTP-75 Mode Vehicle Fuel Economy on Front Wheel Driven Hybrid Source Electrical Vehicle

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ABSTRACT

This paper explores the integration of an electric motor and a conventional internal combustion engine in a hybrid electric vehicle designed for two-wheelers. Recent years have witnessed tremendous effort towards hybrid electric vehicle technologies. The proposed architecture features a front-wheel hub motor driven by a brushless DC (BLDC) motor and a rear-wheel conventional internal combustion engine, effectively minimizing overall mechanical coupling stress. The paper details the design considerations for the required power rating, analyses the dynamics of the front-wheel drive system, and discusses the hardware implementation of the hybrid vehicle. Additionally, the performance of the hybrid system has been evaluated through the FTP75 emission test cycle, with results demonstrating the operational efficiency and performance characteristics of the hybrid IC and front EV motor setup. The FTP 75 driving cycle was then altered under different SOC (state of charge) levels. The simulation data was analysed in comparison with the vehicle velocity, battery current, SOC level, motor RPM and internal resistance of battery for separated axle configuration of both front wheel driven electric vehicle and rear wheel driven IC Engine.

***KEYWORDS** : Hybrid electric vehicle, BLDC motor drives, Road vehicle propulsion, Front wheel drive, FTP75 Cycle, Vehicle performance analysis, Two-wheeler hybrid systems.*

INTRODUCTION

Due to concern over environmental, economic issues and the importance of fuel resources in the world has forced the automotive industry to produce more fuel efficient, low emission vehicles and new drive system technologies. On other hand, the electric vehicle can only be operated for a limited distance. One of the most promising technologies to receive attention is the hybrid electric vehicle (HEV), which consists of two or more energy sources that supply energy to drive the wheels [3] –[5].

The major disadvantage of the parallel hybrid drive train is the powers of the engine and electric motor are coupled together by mechanical coupling, complex structure and its control [3]. In order to avoid mechanical coupling, the separated axle torque combination is proposed and it has advantages of a conventional vehicle. No change in transmission system and original engine on the rear wheel. On other axle electric motor torque is added. The tractive efforts produced by the internal combustion engine and electric motor are added together through the vehicle chassis and road. There is no mechanical coupling between internal combustion engine and electric motor.

A comprehensive analysis of all architectures is presented [1] by testing various functionalities, viz., speed (vehicle, engine, motor), power (engine, battery), battery electrical losses, charge patterns, and fuel consumption.

The performance of all architectures under various dynamic operational conditions and its efficacy is tested for parameters such as the speed of the vehicle, battery charge profile, IC engine/electric motor power profiles, and fuel consumption under dynamic operating

conditions such as continuous acceleration, pulse acceleration, and step-up acceleration is analyzed [8]-[9].

The methodology used in [10] is descriptive, library and analytical. The descriptive aspect is based on identification and definitions and its required materials.

In this paper, the design and construction of a direct-drive, brushless dc motor for use on an electric scooter will be described. Certain design features pertinent to the specific application are highlighted. Experimental results obtained to demonstrate the feasibility of the proposed motor design.

PROPOSED PARALLEL HYBRID ELECTRIC VEHICLE

Parallel hybrid drive train is the separated axle architecture, in which rear wheeler is powered by the engine and front wheeler is powered by the electric motor as shown in Fig. 1.

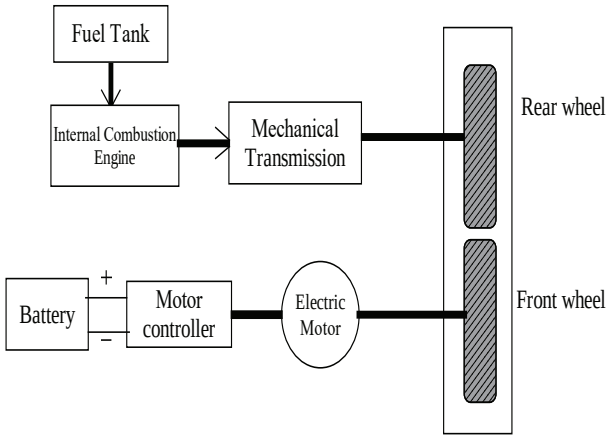

Fig. 1. Parallel hybrid electric drive train

POWER REQUIRED FOR HYBRID ELECTRIC VEHICLE

Force in a vehicle is divided into two parts [7]

Steady State Force

The movement behaviour of a vehicle along its moving direction is determined by all the forces acting on it in this direction. Fig. 2. Shows three types of forces acting on the vehicle.

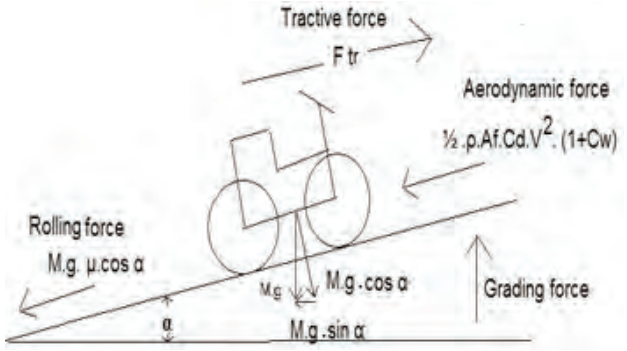

Fig. 2. Free body diagram of vehicle

Wheel rolling resistance

The rolling resistance of tyres on hard surface is primarily caused by hysteresis in the tyre materials. The rolling resistance on soft surface is primarily caused by deformation of the ground surface. The rolling Resistance force F_r can be written as

$$F_r = M.g.\mu.\cos\alpha \quad (1)$$

Where M - Vehicle mass in Kg

g - gravity acceleration in m/s^2

μ - rolling resistance coefficient

α - road angle in degrees

Aerodynamic drag

A vehicle travelling at a particular speed in air encounters a force resisting its motion. This force is referred to as aerodynamic drag Fw

$$F_W = \frac{1}{2}.\rho.A_f.C_d.V^2.(1+C_W) \quad (2)$$

Where ρ - Air density in Kg/m^3

A_f - frontal area of vehicle in m^2

C_d - coefficient of air drag

V - Velocity of vehicle in m/s

C_w - wind speed coefficient

Grading resistance

When a vehicle goes up or down a slope, this force either opposes the forward motion (grade climbing) or helps the forward motion (grade descending). This grading force is usually called grading resistance force

and can be expressed as

$$F_g = M.g.\sin\alpha \quad (3)$$

Where M - Vehicle mass in Kg
g - Gravity acceleration in m/s^2
α - road angle in degrees

The grading force will be positive for up gradient and negative for down gradient.

Dynamic Force

The total vehicle resistance force F_{tvr} defined by equation (4) is the average force which depends on velocity of the vehicle.

$$F_{tvr} = F_g + F_w + F_r \quad (4)$$

$$F_{tvr} = M.g.(\mu.\cos\alpha + \sin\alpha) + \frac{1}{2}.\rho.A_f.C_d.V^2.(1+C_w) \quad (5)$$

Newton's second law states that the acceleration of an object is proportional to the net force exerted on it.

$$M.\frac{dv}{dt} = F_{tr} - F_{tvr} \quad (6)$$

Where Ftr-Tractive effort of the vehicle

$$F_{tr} = \left(M.\frac{dv}{dt}\right) + \left(M.g\,(\mu.\cos\alpha + \sin\alpha) + \frac{1}{2}.\rho.A_f.C_d.V^2.(1+c_w)\right) \quad (7)$$

Therefore, the total vehicle power is

$$P = \left(M.\frac{dv}{dt} + M.g\,(\mu.\cos\alpha + \sin\alpha) + \frac{1}{2}.\rho.A_f.C_d.V^2.(1+c_w)\right).V \quad (8)$$

The main component of the hybrid electric vehicle is its electric power train. The propulsion system is a combination of the electric motor and internal combustion engine. The design variables of electric propulsion are the power rating of suitable electric motor. Hence it is proposed to design an electric drive equivalent to 50 cc internal combustion engine [1]. Power required Pm is obtained from total vehicle force and vehicle velocity which has shown in equation (9)

$$Pm = \frac{M}{2.t_f}\left(V_{rm}^2 + V_{rv}^2\right) \quad (9)$$

Where V_{rm} - rated speed of electric motor
V_{rv} - rated speed of vehicle
t_f - final time to settle steady velocity
ω_r - Angular velocity at the wheel

Constant torque region is from 0 to V_{rm} and Constant power region is from V_{rm} to V_{rv}

Torque required for vehicle is

$$T = \frac{P_m}{\omega_r} \quad (10)$$

The minimum motor power is obtained by differentiating P_m with respect to V_{rm} and setting it to zero gives V_{rm}=0. On the other hand, if the motor operates in the constant torque (force) region during the entire 0 to t_f period, then V_{rm} = V_{rv}. The torque at the wheels of the vehicle can be obtained from the power equation (10).

The parallel HEV system design philosophy, however, requires an extension of the EV system. Following the same procedure [4] as the EV system design, the variables for HEV system design are calculated to fulfil the design constraints which has shown in table 1

In order to design an Electric vehicle equivalent to internal combustion engine, the parameters of internal combustion engine specification in table 1 are substituted in equation 9.

In running condition, increase in power depends on velocity of vehicle, acceleration and grading of vehicle. The requirement of power can be reduced by appropriate choice of vehicle mass and battery weight.

Table 1 Two wheeler specifications for 50cc

Parameter	Symbol	Unit	Value
vehicle mass	M	Kg	160
gravity acceleration	g	m/s^2	9.81
rolling resistance coefficient	μ	no unit	0.013
road angle	α	Degree	0
air density	ρ	Kg/m^3	1.23
frontal area of vehicle	A_f	m^2	0.6
coefficient of air rag	C_d	no unit	0.8
Velocity of vehicle	V	m/s	11.11
wind speed coefficient	C_w	no unit	0.2
Wheel radius	r	m	0.217

The minimum power rating is obtained by differentiating P_m with respect to V_{rm} and settling to zero gives V_{rm}=0. Therefore at time t_f=10 sec, power rating is

$$P_m = \frac{\left(160 \times 11.11^2\right)}{2 \times 10}$$

P_m = 987.45 W

For maximum power rating, vehicle speed and electric motor speed is same at V_{rm} = 11.11 m/s

P_m=1974. 91 W

The power rating is 987.45 W at steady state velocity and at dynamic velocity is 1974. 91 W.

Table 2 BLDC Motor specification

Item	Description
Type	BLDC motor
Mounting	HUB mounting
Rated power	500 watt
Peak power output	1000 watt
Volts	48 v
RPM	1520 RPM
Rated Current	12.5 A
Rated torque	9.18 Nm
Peak torque output	18.36 Nm

The Source of electric energy is obtained with help of batteries. The portable electrical energy source presents the biggest problem in commercialization of EVs. The following are the steps to design the capacity of battery for electric motor

a) To run the electric vehicle for one hour, the required energy in watt-hour is 500 W-hr= (500*1)

b) The depth of discharge (DOD) is the percentage of battery capacity (rated capacity) to which a battery is discharged. E.g. 80%

c) watt-hour =500/.8 =625 W-hr

d) Derated battery bank for ambient temperature at 600 is 1.11 factor

e) watt-hour =625*1.11= 693.75 W-hr at 600

f) watt-hour/voltage= ampere-hour

g) At 48 V, ampere-hour=693.75/48=14.45 Ah

Four 12 V battery is connected in series to obtain 48 V. Theoretical calculation of battery rating is 14 Ah to drive the electric vehicle for one hour.

The main components of electric vehicle include a hub motor, BLDC controller and valve-regulated lead-acid (VRLA) battery.

The wheel hub is part of vehicle that connects the wheel to the suspension arms. A larger hub is required to accommodate BLDC motor and conventional mechanical brake system is used. These are radial-flux Brushless DC (BLDC) machines that have an array of permanent magnets on the inside surface of the hub. The stator windings are attached to the axle, and the hub is made to rotate by alternating currents through these windings. BLDC motor is used as electric drive which is fed by controller from battery.

PWM controller is used for controlling electric motor speed [4].

Depending on condition, hybrid mode, IC engine mode and pure electric mode is selected. Usage of operating modes at real time depends on the power demand, which is commanded by the driver through the engine accelerator, electric motor accelerator and vehicle speed.

INFERENCE

Comparison of internal combustion engine specification with the electric motor rating specification is same as given below

Table 3 Internal Combustion Engine Specification

Parameter	Unit	Value
Type	Stroke	2
Displacement	CC	49.9
Maximum Power	Brake Horse Power (BHP)	2.13
Max Speed	Km/hr	42
Max torque	N.m	3.6

Thus BLDC electric motor is selected for hybrid vehicle to run the vehicle on both steady state and dynamic condition.

Figure 3 shows 48v battery source which delivers power to motor through BLDC converter. The load torque is derived from dynamic load of vehicle. The motor has developed torque which overcomes the load torque of the vehicle.

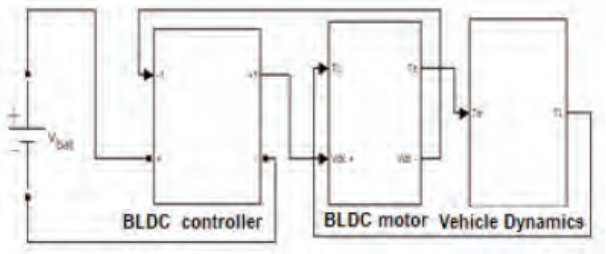

Fig. 3. SIMULINK model of electric vehicle

The hybrid electric vehicle which has two sources. The power sources of the vehicle are internal combustion engine and Electric motor. It can be chosen any of the sources to drive the vehicle. Electric vehicle modelling has been done for simulation and studies. The method of BLDC-FOC voltage control is used for speed variation.

Vehicle acceleration is controlled by varying the Voltage through BLDC controller converter. Variation of motor speed with respect to duty ratio can be seen in graph in fig.7.

The duty ratio of 0.1 to 0.5 operates as a buck converter with voltage range from 4.66v to 24v. Whereas the duty ratio of 0.5 to 0.75 operates as a boost converter with voltage range from 25v to 48v.

ELECTRIC VEHICLE MODELING

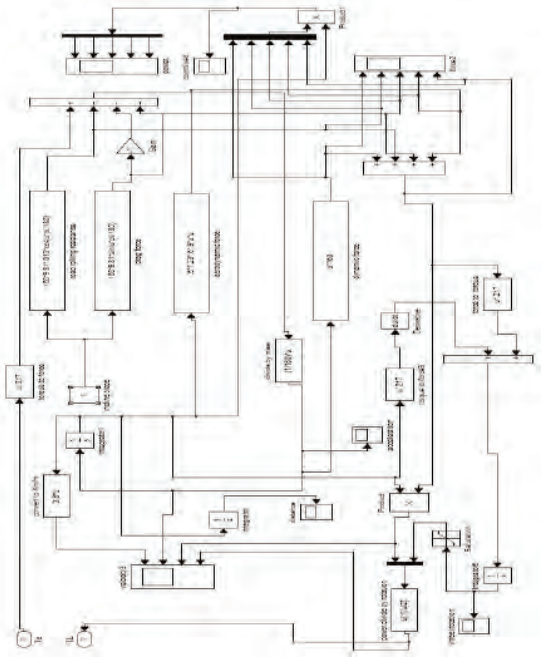

Fig. 4. SIMULINK model of electric vehicle dynamic load

Equations from (1) to (8) are used for electric vehicle modeling. Figure 4 shows the MATLAB SIMULINK model.

The torque Te developed by the motor is converted to driving force by dividing the wheel radius. The dynamic force and the steady state force obtained from equation (8) are added and the total force is called vehicle force. The vehicle force multiplied by wheel radius is the load torque to the motor. The degree of slope can be changed in SIMULINK model. The requirement of power increases as the degree of slope increases.

SIMULATION RESULT

Operation of electric vehicle with 0° slope

The Rated voltage 48v is applied to motor without 6 step control method. BLDC motor characteristic with slope 0° is shown in Figure 6. The motor draws enormous current because of back EMF signal which can used for sensor less motor control. The excessive transient current discharges the battery which subsequently reduces the life of the battery.

The Developed torque reached the peak value due to maximum armature current. It is proposed to use electric motor to run the vehicle in highway road.

The operation of vehicle with IC engine can be used in urban areas where frequent starting and stopping are required.

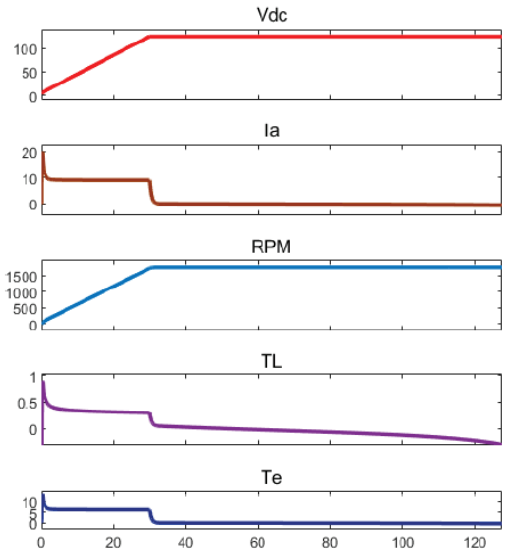

Fig. 5. BLDC motor characteristic at 0° slope

This figure 5 illustrates the developed torque and load torque of an internal combustion (IC) engine and a brushless DC (BLDC) motor, along with the system's speed in revolutions per minute (RPM) and current, during a period from 0 to 30 seconds.

Initially, the IC engine operates to prevent damage to the armature winding and avoid battery discharge, providing necessary torque to overcome inertia. The developed torque increases and reaches a steady-state value of 1.8 N.m. at around 5 seconds. After 30 seconds, the BLDC motor achieves optimal operating conditions, maintaining a constant RPM and current.

This steady state indicates a balanced condition between developed and load torque, ensuring efficient motor operation. The figure highlights the transition from the initial acceleration phase to optimal steady-state performance.

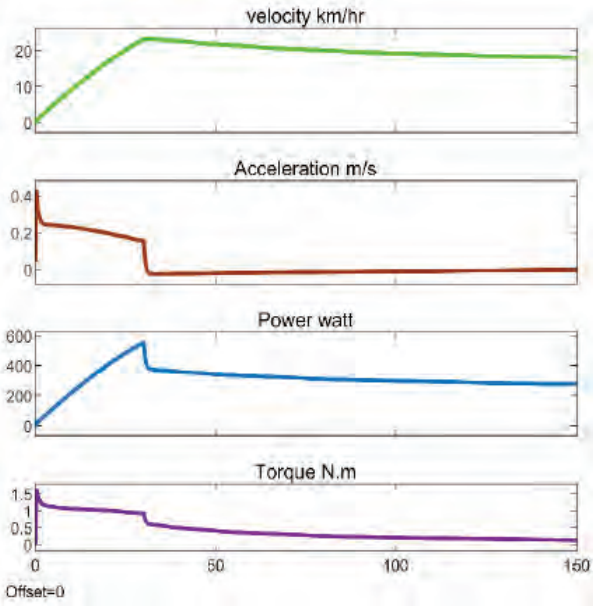

Fig. 6. Electric vehicle performances at 0° slope

From figure 6 steady state is reached after 5 sec which reduces the power requirement to1000 watt. Speed control is achieved by varying the throttle duty ratio of BLDC controller which in turn changing the supply voltage to motor.

Speed control of vehicle in 2° Slope

At the initial condition 0 to 30 sec, vehicle moves in 2° slope. This is shown in Figure 8. After 30 sec, vehicle moves in zero slope. The torque required during of 2° slope is 2.4 N.m. When vehicle reached zero slopes, the required torque is 0.9 N.m.

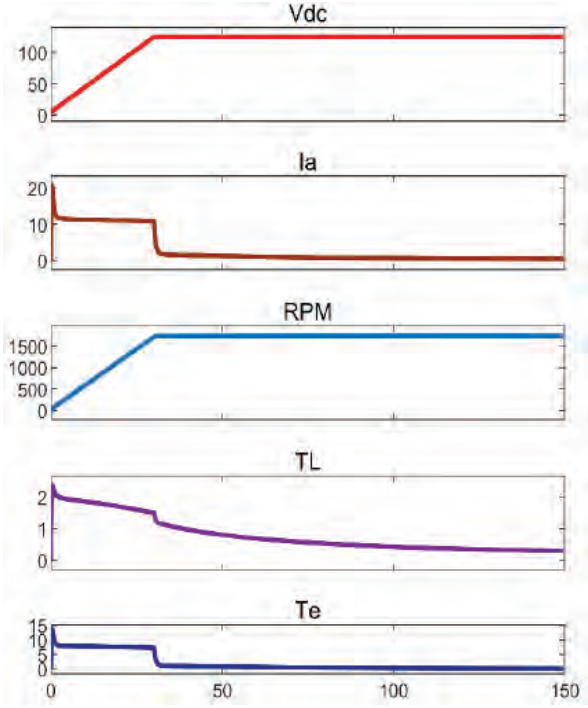

Fig. 7. BLDC motor characteristic at 2° slope

Speed control is obtained by Field oriented control method which will operate by ratio of sinusoidal voltage to controlled frequency in BLDC controller. FOC method is varied by increasing the duty ratio gradually from 0 to 30 sec. Thus the starting current is limited to 20A. Duty ratio is a command signal for complete controlling of BLDC motor.

There is a variation in supply average voltage from 0 to 30 secs which represents dynamic force. The FOC method voltage becomes constant from 30 to 50 secs which represents steady state force. The motor speed reached 1450 rpm in 30 secs because FOC method votage attains rated value of 48. Te is the developed torque which follows armature current. Load torque TL is calculated from vehicle's dynamic load.

During condition, the hybrid drive can be used with both sources for propulsion of vehicle. The power rating of motor can be reduced by operating the vehicle with combined sources while negotiating the gradient condition of road.

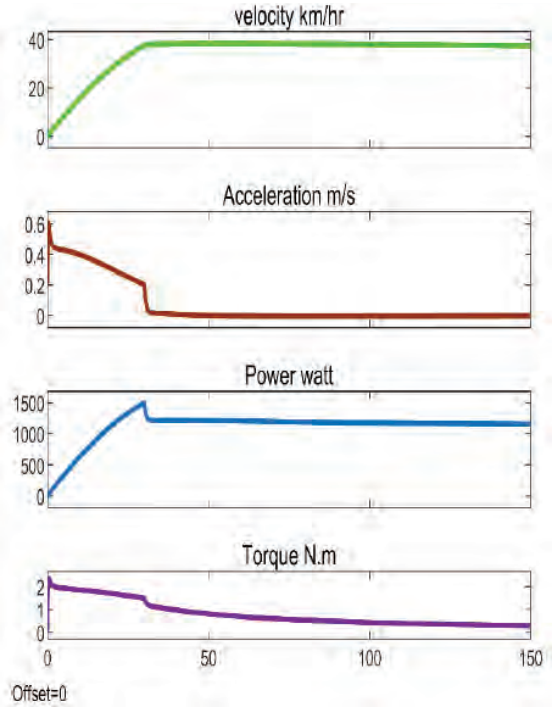

Fig. 8.Electric vehicle performances at 2° slope

Figure 8 shows a steady state velocity is reached at 30 sec when vehicle moves in zero slope.

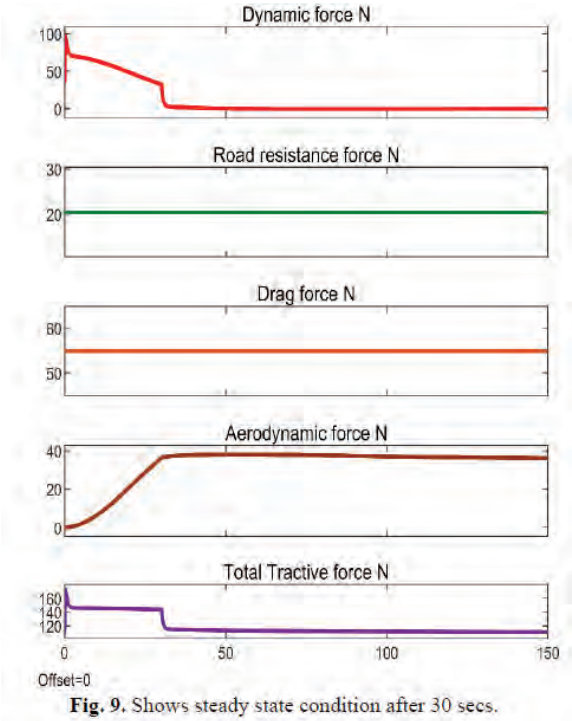

Fig. 9. Shows steady state condition after 30 secs.

Fig. 9. Shows steady state condition after 30 secs.

The dynamic power reaches to zero value. Total tractive power is calculated from dynamic power, road resistance power, drag power and aerodynamic power.

PERFORMANCE OF ELECTRIC MOTOR MODE ON FRONT WHEEL DRIVE

Total weight of vehicle including electric motor, battery, and internal combustion engine and driving person is 189 Kg.

Electric motor input voltage and input current value corresponding to vehicle speed is noted. Constant power loss and copper power loss gives total power loss. Electric motor output power is calculated from motor input power by subtracting total power loss.

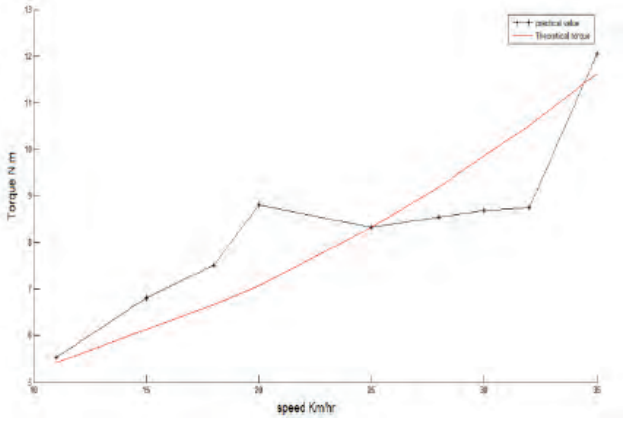

Fig. 10. Comparison of practical and theoretical value of torque on plain surface for electric motor alone

The comparison of electric motor torque and theoretical torque required for vehicle performance at steady state condition on plain surface is shown on fig. 10.

PERFORMANCE OF HYBRID MODE

Engine operating point is controlled by the engine throttle. With fixed engine speed at 25 Km/hr, then increasing the electric motor throttle angle will cause the vehicle speed to increase. Thus the engine operating point can be potentially controlled within its fixed region by instantaneously controlling of electric motor.

Hybrid mode on Plain surface

The propelling torque acting on the driven wheel can be expressed as

$$T_{wheel} = T_{engine} + T_{motor} \quad (11)$$

$$T = \frac{bhp \times 5252}{rpm} \quad (12)$$

$$bhp = weight \times \left[\frac{velocity}{234}\right]^3 \quad (13)$$

Where

Weight - total weight of a vehicle including person

bhp – engine brake horsepower

Velocity – vehicle speed in Km/hr

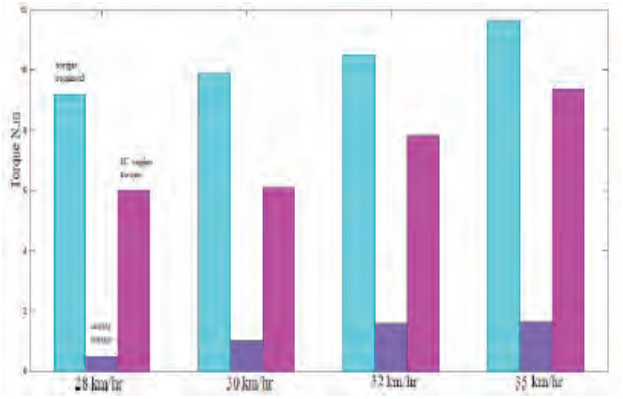

Fig. 11. Comparison of practical and theoretical value of torque on plain surface for hybrid mode

Engine torque is calculated from equation (12) from vehicle tire rotation per minute and brake horse power. Brake horse power value is calculated from equation (13) from vehicle speed in km per hour and total weight of vehicle.

Hybrid mode on slope surface

In an engine alone powered vehicle, a multi gear transmission is used to modify the engine torque speed profile to make the tractive effort speed profile on a driven wheel. Whereas in hybrid mode, Electric motor acts as supporting torque source at acceleration and hill climbing, in addition to the engine torque source at hybrid mode.

Bar chart diagram shown in Fig.12. Presents contribution of total torque required, electric motor torque and internal combustion engine torque.

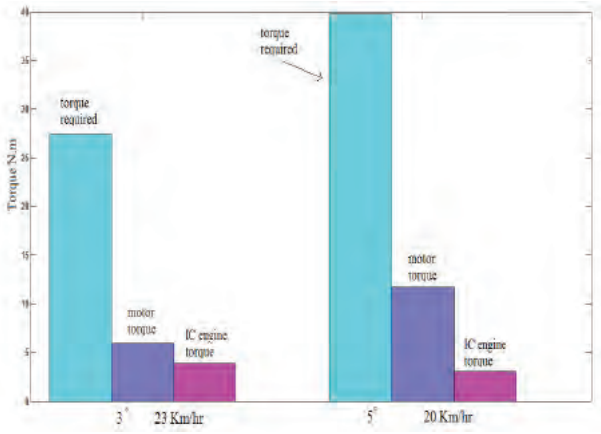

Fig. 12. Comparison of practical and theoretical value of torque on slope surface for hybrid mode

OPERATION OF ELECTRIC MOTOR DRIVE IN FRONT WHEEL

Developed parallel hybrid drive train is the separated axle architecture, in which rear wheel axle is powered by the internal combustion engine and the front wheel by the electric motor. Rear wheel drive is more difficult in handling on low grip surfaces like wet road, ice, snow and gravel.

The front wheel axle architecture offers some of the advantage of a convention vehicle. It keeps the original engine and transmission unaltered and adds a torque source from electric motor.

Fig. 13. Developed hybrid electric vehicle setup-Front wheel

Placing the mass of the drive train over the front driven wheel which moves the centre of gravity farther forward than a comparable rear-wheel drive system which improves traction and directional stability on wet, snowy, or icy surfaces. Disadvantage of front wheel drive is stability aspect while making U turn on road. Hardware setup is shown in Fig.13.

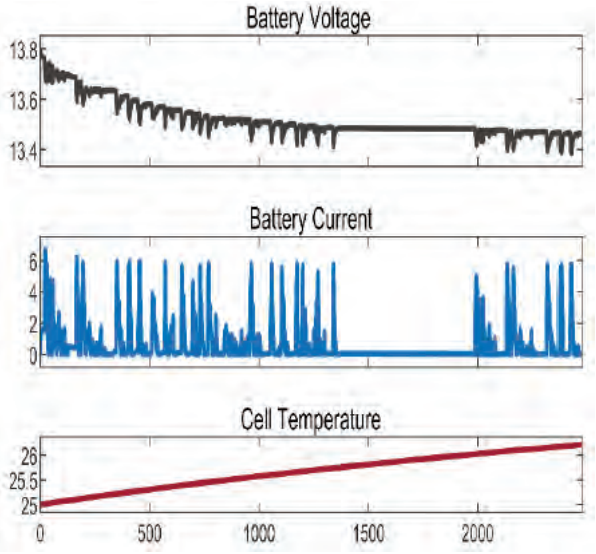

Fig.14. Individual battery cell in FTP75 (2474 seconds)

This figure 14 presents the performance data of an individual battery cell during the FTP75 emission test cycle, which lasts 2474 seconds, under hybrid operation. The battery cell was subjected to full stress testing. Throughout the test, the cell temperature was maintained between 25-26°C.

The voltage across the battery cell became constant after approximately 500 seconds, indicating stabilization under the testing conditions.

The figure 14 illustrates the temperature and voltage profiles of the battery cell over the course of the emission test cycle.

This figure 15 illustrates the State of Charge (SoC) and internal resistance of a battery throughout the 2474-second FTP75 emission test cycle under hybrid conditions. After an initial period, the internal resistance stabilized post-500 seconds, while the SoC showed a steady decline, indicating consistent energy usage. under hybrid operation, involving both an IC engine and a BLDC motor.

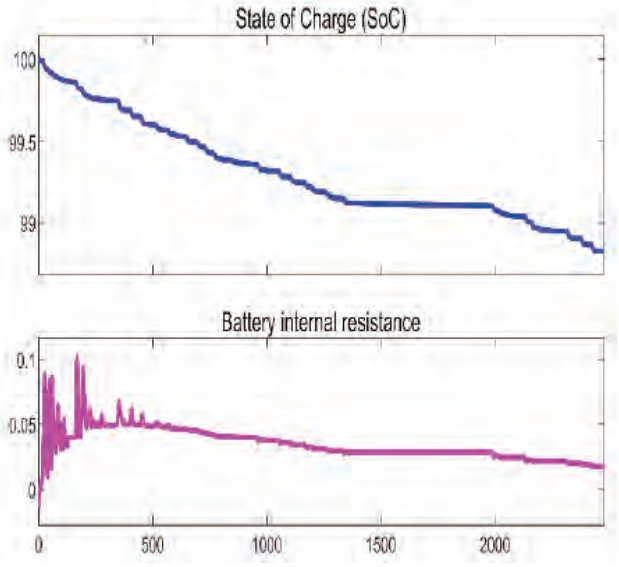

Fig.15. SoC and internal resistance of battery in FTP75 (2474 seconds)

This figure 15 highlights the battery's performance stability and efficiency during the test.

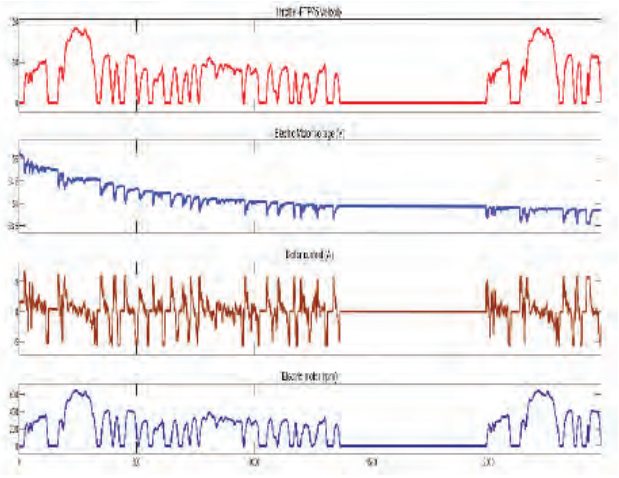

Fig. 16. BLDC motor characteristic in FTP75 (2474 seconds)

This figure 16 illustrates the BLDC motor characteristics during the 2474-second FTP75 emission test cycle. The throttle velocity was directly related to the motor's RPM.

Initially, the motor voltage spiked at 55 volts but then gradually decreased to 54 volts and became unstable, reflecting the motor's dynamic response to varying throttle inputs under the test condition.

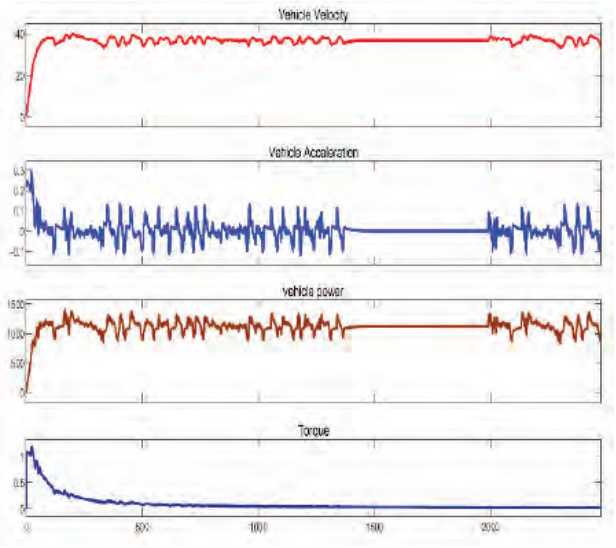

Fig. 17. Electric vehicle performances in FTP75 (2474 seconds)

This figure 17 details the performance metrics of an electric vehicle operating under hybrid conditions with an internal combustion (IC) engine and a brushless DC (BLDC) motor during the 2474-second FTP75 emission test cycle.

After 500 seconds, the torque output stabilizes, while the vehicle's velocity achieves a peak of 40 km/h. Power delivery to the vehicle fluctuates between 1000 and 1500 watts, demonstrating the dynamic interplay between the IC engine and BLDC motor in maintaining optimal performance throughout the test cycle.

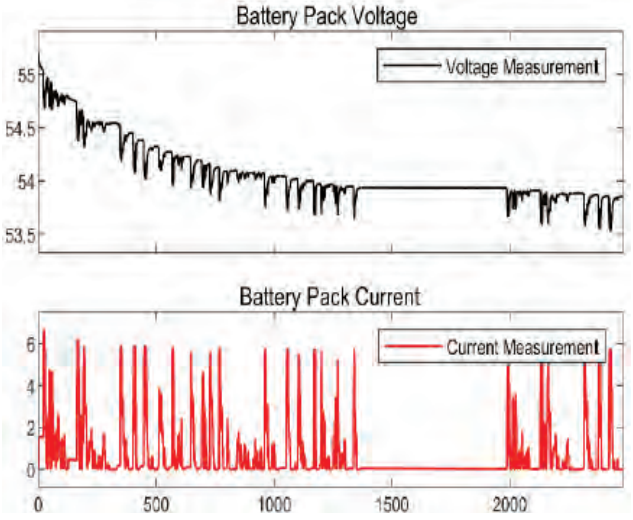

Fig. 18. Battery performance of Pack in FTP75 (2474 seconds)

This figure 18 illustrates the performance of the battery pack during the 2474-second FTP75 emission test cycle under hybrid conditions with both an internal combustion engine and a brushless DC motor.

The battery pack current fluctuates around 6 amps, while the voltage initially starts at 55 volts. After 1000 seconds, the voltage becomes unstable, fluctuating around 54 volts, reflecting the battery pack's dynamic response to hybrid operation.

This figure 19 displays the steady-state power characteristics of an electric vehicle during the 2474-second FTP75 emission test cycle, under hybrid operation with an IC engine and a front electric BLDC motor.

After 30 seconds, road resistance power stabilizes around 200 watts, vertical resistance power around 600 watts, while aerodynamic power fluctuates between 200 and 400 watts. Total tractive power varies between 1000 and 1500 watts.

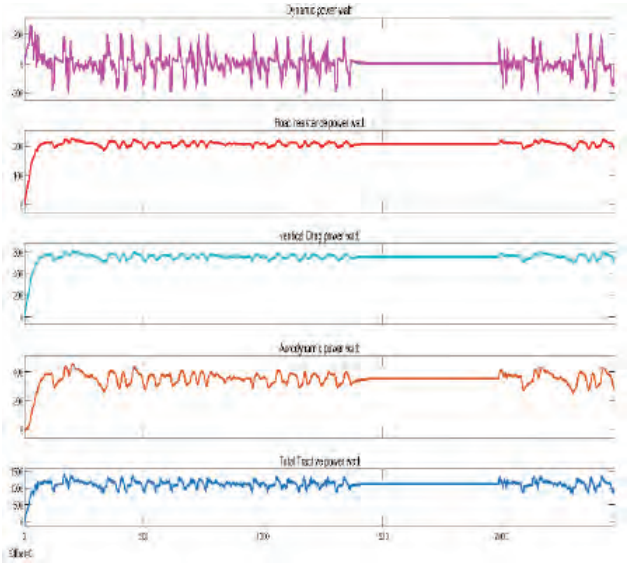

Fig. 19. Shows steady state condition after 30 secs in FTP75 (2474 seconds)

These parameters are influenced by the throttle input, reflecting the vehicle's performance in hybrid mode.

CONCLUSION

Test has been conducted for pure electric motor vehicle mode and hybrid mode for both plain surface and gradient surface. Practical value of torque is calculated

and is compared with theoretical value for different speed. The results indicate that the proposed system can operate at fuel economy by implementing the rule-based energy management strategy along with the equivalent consumption minimization strategy, which shows the feasibility and effectiveness of the configuration and control strategies for separated axle front and rear wheel drive vehicle.

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Smart Soft Starter for Three Phase Induction Motor with Minimized Inrush Current

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ABSTRACT

Induction motors are used in industry in variety of applications such as blowers, fans, compressors, pumps, mixers, crushers and grinders etc. Direct Torque Control (DTC) is used for speed adjustment of induction motors and DTC is known to produce quick and robust response in AC drives. However, during steady state, notable torque, flux and current pulsations occur. They are reflected in speed estimation, speed response, and also in increased acoustical noise. This paper introduces GA tuned fuzzy logic control system to control the torque and flux of the induction motor based on space vector modulation for induction motor sensor less drives. It is able to reduce the acoustical noise, the torque, flux, current and speed pulsations. Finally, simulated results show that the proposed controller provides high performance characteristics and is robust with regard to plant parameter variations and external load disturbance. The proposed control techniques, simulations, implementation data, and the results with DTC are given and discussed. It is concluded that the proposed control techniques produce better results for steady state operation than the DTC.

***KEYWORDS** : Soft starter, Direct torque control, Fuzzy logic, Genetic algorithm, Total harmonic distortion.*

INTRODUCTION

Induction motors are being applied today to a wider range of applications requiring variable speed. Generally, variable speed drives for Induction Motor (IM) require both wide operating range of speed and fast torque response, regardless of load variations. This leads to more advanced control methods to meet the real demand. The conventional control methods have the following difficulties

1. It depends on the accuracy of the mathematical model of the systems
2. The expected performance is not met due to the load disturbance, motor saturation and thermal variations.

Advanced control based on artificial intelligence technique is called intelligent control. Every system with artificial intelligence is called self-organizing system. On the 80th decade the production of electronic circuits and microprocessors with high computation ability and operating speed has grown very fast. The high power, high speed and low cost modern processors like DSP, FPGA and ASIC IC's along with power technique switches like IGBT made the intelligent control to be used widely in electrical drives. Intelligent control, act better than conventional adaptive controls. Artificial intelligent techniques divide two groups: hard computation and soft computation [1]. Expert system belongs to hard computation which has been the first artificial intelligent technique. In recent two decades, soft computation is used widely in electrical drives. They are,

1. Artificial Neural Network (ANN)
2. Fuzzy Logic (FL)
3. Genetic Algorithm (GA)

Neural networks and fuzzy logic technique are quite different, and yet with unique capabilities useful in information processing by specifying mathematical relationships among numerous variables in a complex system, performing mappings with degree of imprecision, control of nonlinear system to a degree not possible with conventional linear systems. Fuzzy logic is a technique to embody human-like thinking into a control system [2]. A fuzzy controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions. Fuzzy control system consists of four blocks as shown in Fig. 1.

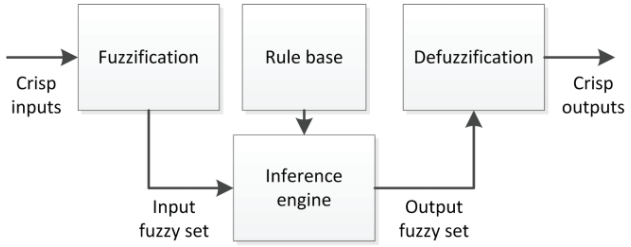

Fig.1 Basic block diagram of Fuzzy logic control

Due to advances in power electronic switches and microprocessors, variable speed drive system using various control technique have been widely used in many applications, namely Field oriented control or vector control, Direct torque control, sensorless vector control [3].

DIRECT TORQUE CONTROL

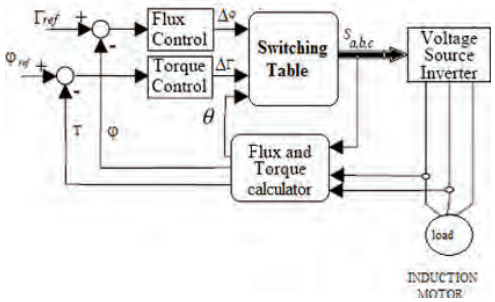

Fig. 2 Direct Torque Control block diagram

The Direct Torque Control (DTC) scheme is shown in fig.2 which is very simple. In its basic configuration it consists of DTC controller, torque and flux calculator and VSI. In principle, the DTC method selects one of the inverter's six voltage vectors and two zero vectors in order to keep the stator flux and torque within a hysteresis band around the demand flux and torque magnitudes [4].

The torque produced by the induction motor can be expressed as shown below

$$T = \frac{3}{2}\frac{P}{L_s}\frac{L_m}{L_r}\left|\overline{\lambda_r}\right|\left|\overline{\lambda_s}\right| sin \propto \quad (1)$$

This shows the torque produced is dependent on the stator flux magnitude, rotor flux magnitude and the phase angle between the stator and rotor flux vectors [5]. The induction motor stator equation is given by

$$\overline{V_s} = \frac{d\overline{\lambda_s}}{dt} - \overline{I_s} r_s \quad (2)$$

can be approximated as shown below over a short time period if the stator resistance is ignored, then

$$\Delta\overline{\lambda_s} = \overline{V_s}.\Delta t \quad (3)$$

If a voltage vector is applied that changes the stator flux to increase the phase angle between the stator flux and

rotor flux vectors, then the torque produced will increase [6-8]. Two problems are usually associated with DTC drives which are based on hysteresis comparators are:

i. Variable switching frequency due to hysteresis comparators used for the torque and flux estimators
ii. Inaccurate stator flux estimations which can degrade the drive performance.

Some schemes have managed to maintain an average constant switching frequency by utilizing apace vector modulation, predictive control, and dead beat control [9-10]. All of these techniques increase the complexity of the drive systems.

VOLTAGE SOURCE INVERTER

A voltage source inverter supplies the motor and it is possible to control directly the stator flux and the electromagnetic torque by the selection of optimum inverter switching modes [11]. The desired stator flux is

obtained by using space vector modulation technique. The space vector modulation is described using voltage source inverter which feeds a three phase induction motor. The inverter converts the dc signal into ac signal through power electronic devices such as MOSFET (Metal Oxide Semiconductor Field Effect Transistor) switches. The voltage source inverter is shown in Fig.3.

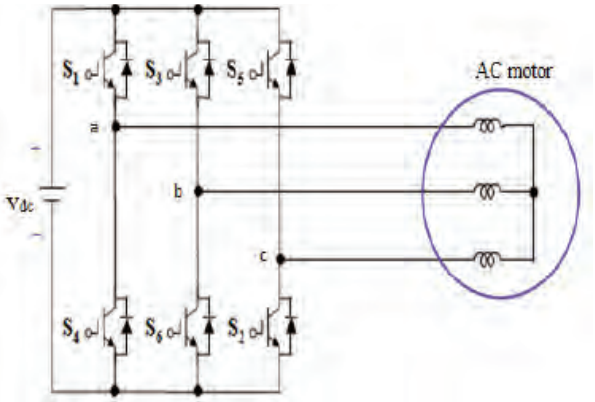

Fig. 3 Voltage source inverter

By neglecting the stator resistances, the flux equation is expressed as

$$\frac{d\varphi_s}{dt} = V_s \quad (4)$$

Where, V_s and φ_s are the stator voltages and flux respectively. From eqn,

$$\Delta\varphi_s = V_s \Delta t \quad (5)$$

Hence the stator flux is proportional to the stator voltage

The voltage source inverter depends on the ON-OFF switching state of each MOSFET. These are eight switching states. The ON state is indicated by the number 1 and OFF state is indicated by the number 0. In that, two of the switching states have null voltage and so zero flux states [12]. The outputs of the voltage source inverter are fed to the three phase induction motor. Space Vector Pulse Width Modulation (SVPWM) directly transforms the stator voltage vectors into PWM signals. This technique gives the switching scheme of six power switches of three phase inverter. It uses eight switching modes of inverter to control the stator flux to approach the reference flux circle and attains higher control performance [13- 15]. The switching states of the inverter are determined using modulation technique. The modulation technique approximates the reference voltage by a combination of the eight switching patterns. The stator voltage vectors can be chosen depending on the eight switching states of the inverter [16].

The applied voltage vector as shown in the Fig. 3 determines the change in the stator flux vector as shown in Fig. 4. The eight switching modes corresponds to eight space voltage vectors that contains six non- zero vectors and two zero vectors. The applied phase voltage corresponds to eight combination s on to the d-q plane by performing d-q transformation. The eight vectors are called basic space vectors [17]. They are denoted by V1 (100), V2 (110), V3 (010), V4 (011), V5 (001), V6 (101), V7 (111) and V0 (000) shown in fig 5. The six non- zero vectors divide equally the d-q plane into six sectors. The angle between two adjacent vectors is 60 degrees [18-20].

PROPOSED SCHEME

The proposed block diagram is shown in fig. 4. The measured voltage and current from the inverter is given to the torque and flux calculator and the abc variables are transformed to dq variables. The calculated torque and flux are given to the intelligent controller (fuzzy logic and genetic algorithm). The torque and flux are fuzzified and optimized. After optimization the outputs are defuzzified and again dq variables are transformed into abc variables and are given to the switching circuit.

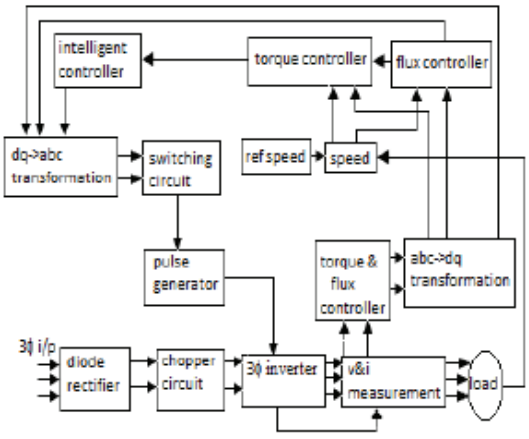

Fig. 4 Block Diagram of proposed system

FUZZY LOGIC CONTROLLER

To obtain fuzzy based model of the motor, the training system derives information from two main sources,

i. The static flux linkage curves of the motor, which provides important information about the electromagnetic characteristics of the motor

ii. The dynamic real time operating wave forms of the motor, which can include real-time operating effects, such as mutual coupling between phases, temperature variations, eddy currents and skin effects. During the training phase, each input-output data pair, which consists of a crisp numerical value of measured flux linkage, current, angle and voltage is used to generate the fuzzy rules.

To determine a fuzzy rule from each input-output data pair, the first step is to find the degree of each data value in every membership region of its corresponding fuzzy domain. The variable is then assigned to the region with the maximum degree. When each new rule is generated from the input-output data pairs, a rule degree or truth is assigned to that rule, where this rule degree is defined as the degree of confidence that the rule does in fact correlate to the function relating voltage and current to angle. In the developed method a degree is assigned which is the product of the membership function degree of each variable in its respective region. Every training data set produces a corresponding fuzzy rule that is stored in the fuzzy rule base. Therefore, as each input output data pair is processed, rules are generated. A fuzzy rule or knowledge base is in the form of two dimensional tables, which can be looked up by the fuzzy reasoning mechanism. Fig. 5 shows the various normalized membership functions for input and output variables. A fuzzy logic controller operation is based on the rules formed.

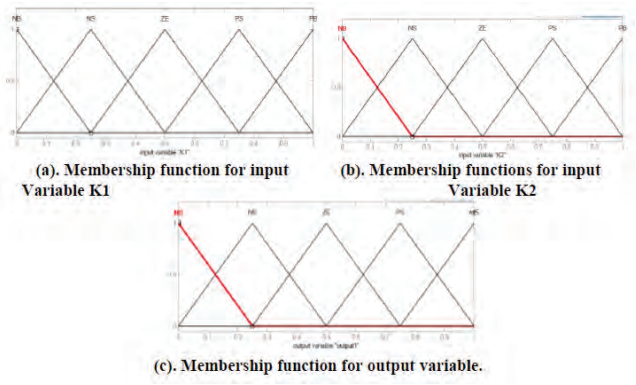

Fig. 5 Various membership functions for input and output variable

SIMULATION RESULTS

Input variables are required to be normalized with ranges of membership functions specified. Suitable normalization has direct influence in results in optimal and faster response. Fig. 6 shows the membership functions and the output of the fuzzy logic controller. The fuzzy logic controller operation is based on the control operation rules which are shown in Table 1.

Table 1 Fuzzy controller operation

Error Δe	NB	NS	ZE	PS	PB
NB	ZE	PS	PS	PB	PB
NS	NS	ZE	PS	PS	PB
ZE	NS	NS	ZE	PS	PS
PS	NB	NS	NS	ZE	PS
PB	NB	NB	NS	NS	ZE

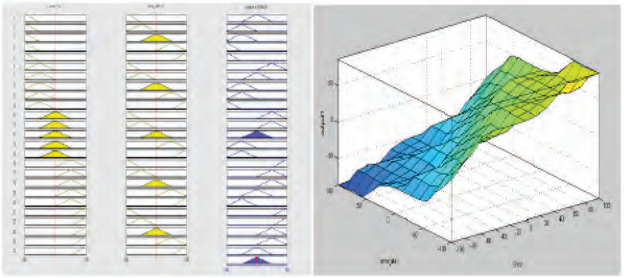

Fig. 6 Fuzzy controller output (a). Rule view and (b). Surface view

DISCUSSION ON RESULTS

The results of simulink diagram of induction motor stator currents, rotor speed and torque response of DTC, FLC and GA are shown below in fig 7 and fig.8 and a better performance is obtained. Fig. 7 shows the steady state current response of GA which has negligible ripple in stator current while as with FLC in Fig .7, the stator current has considerably very high ripple. From fig. 8, it is shown that the speed response of fuzzy logic controller has a steady state error even though it is robust to load disturbances whereas the steady state speed response of GA is achieved at 1430 rpm. Fig. 9 shows the torque response of FLC and GA.

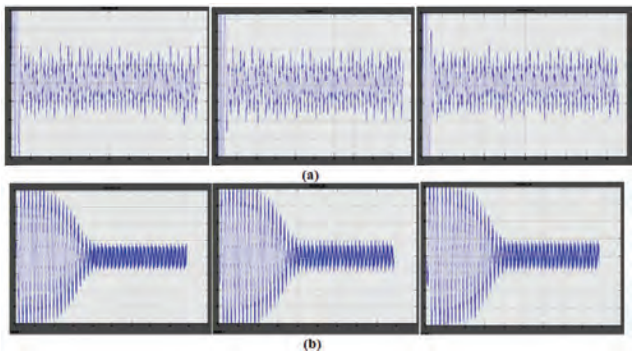

Fig. 7 Three phase stator current of DTC (a). With fuzzy and (b). GA tuned fuzzy system

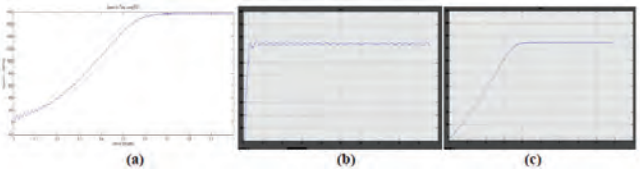

Fig. 8 Speed response for various control schemes (a). DTC, (b). DTC with Fuzzy and (c). DTC with GA

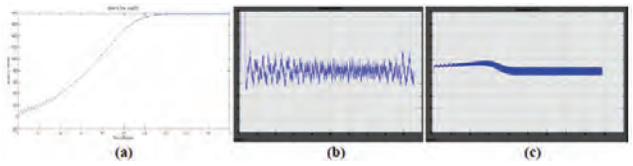

Fig. 9 Torque response for various control schemes (a). DTC, (b). DTC with Fuzzy and (c). DTC with GA

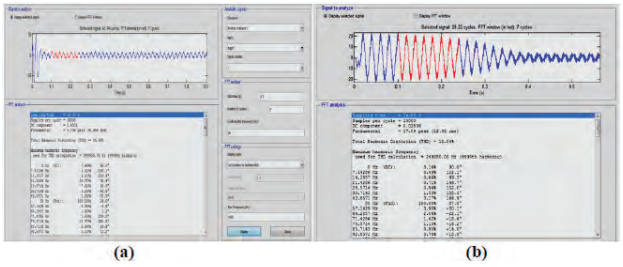

Fig. 10 FFT analysis (a). FLC and (b). GA tuned FLC

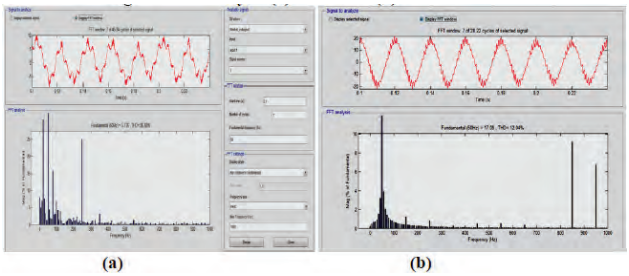

Fig. 11 THD analysis (a). FLC and (b). GA tuned FLC

It is seen that the ripple in torque is less than 5Nm in GA and with fuzzy logic controller the response is about 10N- m at the same operating conditions. Fig. 10 and Fig. 11 show the FFT analysis of the output response using FLC and GA. The total harmonic reduction using FLC is 26.58% whereas using GA it is 12.04%. Both figures show the bar representation of harmonics reduction using FLC and GA. The harmonics are well reduced using GA when compared to FLC.

CONCLUSION

The proposed torque controller gives maximum torque over the entire speed range. In the steady state, the efficiency of the induction motor is increased. The validity of the proposed controller is confirmed through the simulation results. To implement it in the laboratory various parameters like rotor flux, rotor current and operating points, rotor parameter tuning are to be estimated using Genetic Algorithm. The proposed torque control system can be useful for the variable speed drive system.

The torque ripple is significantly reduced when fuzzy controller is in use. The fuzzy controller provides the desired amplitude according to the torque ripple level and operating condition, as it is shown in the paper. It is seen that the steady state performance of the DTC with fuzzy controller is much better than that of the DTC without fuzzy controller.

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Tuning-Fork shape Slot Printed Monopole Antenna with Dual-frequency Resonance having better VSWR for ISM band and WiMax Applications

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ABSTRACT

This research proposes a dual-resonance fork-shaped slotted monopole antenna design and simulation study. The antenna's design has a ground plane at the bottom and a tuning-fork-style slotted patch on the front that serves as a resonator and is supported by a substrate layer which is sandwiched between ground and patch. The CST microwave studio simulation application is used to study the properties of the antenna. The designed antenna is fed with printed monople feed making the antenna as monopole antenna. At resonances of 2.3 GHz, 2.4 GHz, and 5.6 GHz, the findings demonstrate the dual-band performance with a simpler structure and improved return loss (RL) having bandwidths of 349 MHz, 297 MHz, and 285 MHz. The results are in contrast to traditional antenna design. Hence, it is appropriate to use the suggested antenna for WiMax and ISM band applications.

***KEYWORDS** : Monopole, ISM, Radiation, Return loss, Antenna.*

INTRODUCTION

Next-generation technological developments are connected by wireless communication. The majority of them will be made possible by contemporary wireless technologies that are Internet of Things (IoT), WiFi, WiMax capable. The most effective way to get high-quality communications is via antennas. Nowadays, in order to target many technologies with a single antenna, exchange of data communication requires more bandwidth. A device that transmits or receives radio waves is referred to as an antenna or aerial, under IEEE Std 145-1983, the IEEE Standard Definitions of Terms for Antennas. When paired with a transmitter or receiver, the antenna acts as a link between electrical currents and radio waves moving across space on metal conductors [1-6]. Every day, more and more individuals use the wireless network to connect. Different frequency bands are allotted to WLAN, 5G, WiMax etc. These assigned frequency bands are set and globally standardized. The most demanding of these is WLAN, which is widely accessible on college campuses, in public areas, in commercial settings, etc. WLANs employ the IEEE 802.11 standard in which WLAN frequencies in the 2.4 GHz and 5 GHz bands are often used. IEEE WLAN protocol 802.11a/h/j/n/ac uses 5-6GHz frequency channels [7]. The frequency 5.6 GHz is used by several wireless technologies on modern mobile devices, including laptops and smart phones. IEEE 802.11a Wireless Local Area phones is one example; they may enhance their Internet connectivity and 5.725-5.825 GHz by using external patch antennas put in a network (WLAN) with band frequencies of 5.15-5.35 GHz gear. Networks are also based on WiMax-Globally accepted technologies like WLAN and WMAN standards. Sports, medical, and military applications are the focus of the new IMT-2000 OFDMA TDD standard [8, 9]. Low profile antennas that are very practical may now be constructed by using modern printed circuit manufacturing processes. Microstrip antennas are low-cost planar antennas radiating its energy outwards the patch egdes. They are low-profile antennas may be created by etching the antennas on soft or hard substrates using printed circuit methods. Although the antenna's construction

can be three-dimensional (e.g., wrapped around an object), the components are often flat, which is why they are also known as planar antennas. Such antennas are used in satellites, spacecraft and missiles due to their aerodynamic profiles, size, weight, cost, and performance. [10-11, 14-19]. This paper deals with simple design of printed monopole antenna designed on FR-4 dielectric material having the bottom corners cut with introduction of tuning fork shape slot inside the patch fed with line feed. This antenna furthermore has a tiny ground plane on the back of the substrate that is coupled to a 50 ohm SMA connection in order to provide a contact feed arrangement. The developed antenna may be used for dual-use wearable antenna applications, WiMax band, and ISM.

DESIGN OF CONVENTIONAL ANTENNA AND TUNING-FORK SHAPE SLOTTED PRINTED MONOPOLE ANTENNA

The L, S, and C band frequency bands are covered by the printed monopole antenna. A dielectric layer of FR4 with a 0.035µm square copper thin patch serving as a conductor and a other side a small copper ground plane is fabricated on the substrate's back plane. The CST microwave simulator is used to get simulation results where the square monopole antenna works at 2.3 GHz, 2.4GHz and 5.6GHz. Dual resonances appear when the tuning fork slotted patch is fed with line feed mechanism, which has a better current flow across the patch and ground plane. The equations given in [12-13] are used to find the different dimensions of patch length and width.

When building a rectangular patch antenna, the following three aspects are essential: a) Operational frequency (fo): Antenna resonance frequency selection needs to be done correctly as a first aspect in design. For WiMax and ISM applications, the wireless communication systems of this architecture operate on frequencies ranging from 2 to 6 GHz. As a result, this frequency range must be compatible with the antenna's design. For this design, 2.4 GHz was chosen as design frequency. b) Dielectric constant of substrate (εr): The dielectric material for our design was FR4, because , its εr of 4.4 make it a better selection to get improved bandwidth and also it reduces the size of the antenna. c) Height (h) of the dielectric substrate: In order to be utilized in mobile phones, the microstrip patch antenna must be small and light. The dielectric substrate's height of 1.6 mm is therefore chosen.

000The patch, substrate, and ground plane dimensions are computed using the design equation previously discussed. The square patch is 13 x 13 mm in length and width is designated as L x W as seen in Fig. 1 (a). The microstrip feedline length and width is represented as (Lf x Wf) is (16 x 1.3 mm). The dimension of substrate's length and width for the suggested design is indicated as (Ls x Ws) is (16 x 30 mm), whereas in conventional design, the copper on the rear-side of dielectric material is given as (Lg x Wg) (16 x 1 mm) in length and width. A conducting strip is connected straight to the edge of the microstrip square patch in order to feed the antenna using the line feed mechanism. This feed configuration has the advantage of enabling the feed to be etched into the same substrate to form a planar structure, and the conducting strip is thinner than the patch. The extended version of conventional antenna is as shown in Figure 1 (b) which is now etched with tuning fork type slotted printed monopole antenna (TFSPMA) retaining the ground plane dimension as that of conventional design having the dimension as given in table 1. This type of new design gives the dual response with better VSWR.

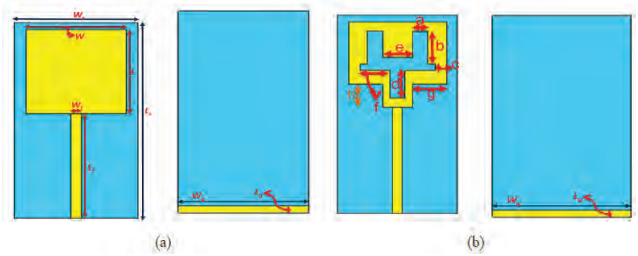

Fig. 1. Geometry of printed monopole square shape antenna a) conventional design, b) tuning fork type slotted monopole antenna (TFSPMA)

Table 1. Parameters and its values for the tuning fork type slotted monopole antenna (TFSPMA)

Designated parameters	Value (in mm)
a	2
b	5
c	1
d	4.13
e	4

f	4
g	4.5
h	4.2
L x W	13 x 13
L_f x W_f	16 x 1.3
L_g x W_g	16 x 30 mm

RESULTS & DISCUSSION

To obtain a better performance of antenna, both the feed and the antenna must send as much power as feasible for any particular antenna to perform properly. The graph of returnloss(RL) vs frequency is displayed in Fig. 2. To decrease reflection wave loss and optimize transmitting power, the measured return loss (RL) value is set to the lowest possible, thus improving the antenna's performance. as per the figure 2, approximately 349 MHz at 2.4 GHz, 297 MHz, and 285 MHz at resonances 2.3 GHz and 5.6 GHz, displaying dual band characteristics, are obtained.

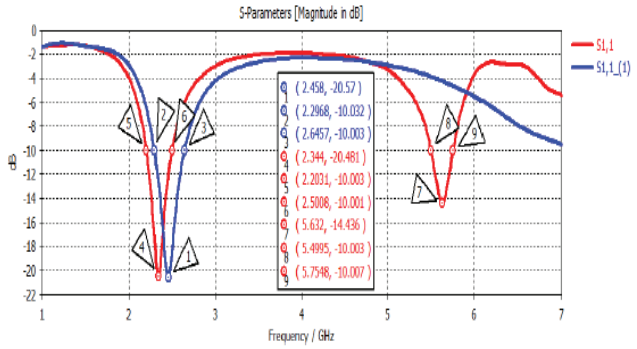

Fig. 2. RL characteristics (Blue curve: Conventional design, Red curve: TFSPMA)

According to the surface current distribution shown in Figure 3(a), there is a current portion on the patch width that functions as a radiating edge and produces the first resonance at 2.4GHz. Since the same amount of current passes through both the feed section and the partial ground plane, it is also clear that they affect the single band resonance. It is clear from Fig. 3(b) that the tuning fork slotted patch design, with feed and ground plane having small copper portion on the back side of the dielectric, produces second resonance, that depicts the dual band characteristics.

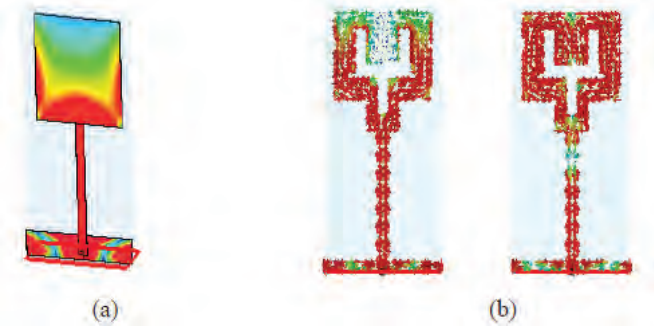

Fig. 3. Surface current distribution. a) conventional design, b) tuning fork type slotted monopole antenna (TFSPMA) for two resonances

The conventional antenna's far field radiation plots in 2D and 3D are displayed in Fig. 4(a, b). These plots illustrate the broadsided characteristics, where the front side of the patch has the highest radiation and the sides have null radiation. Another factor contributing to the radiation is the existence of a copper patch on the ground plane. The 2D and 3D far field radiation plots of a tuning fork-shaped monopole antenna with broadsided characteristics at two independent resonances are displayed in Fig. 5(a, b). When the antenna is oriented toward the opposite side of the receiver, the radiation is in null and in the front side of the slotted patch exhibits the highest radiation with. Another factor contributing to the radiation is due to etching of copper patch on the ground plane. Figure 6 displays the suggested design's VSWR vs frequency graph. It can be seen that, the VSWR of 1.2 and 1.1 are obtained at individual resonances, which are lower than the VSWR of 1.5. This suggests better impedance matching and a reduction in reflected power returning to the source.

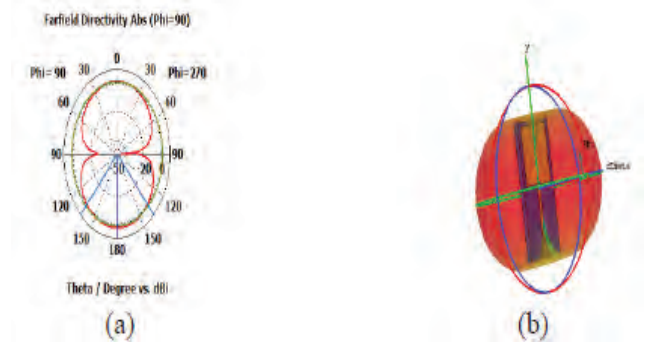

Fig. 4. Conventional antenna a)2D pattern, b) 3D pattern

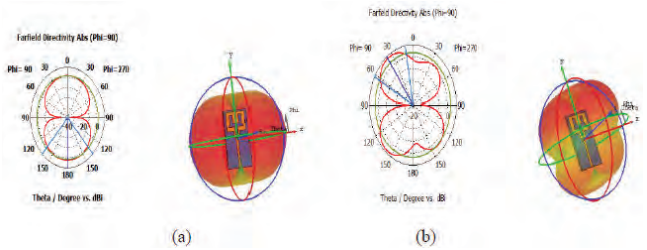

Fig. 5 tuning fork type slotted monopole antenna (TFSPMA).radiation pattern. a) 2D pattern, b) 3D pattern

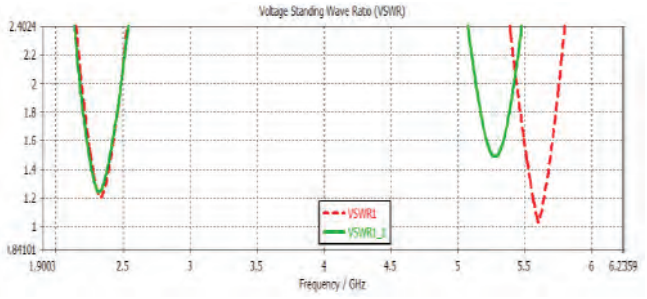

Fig.6. VSWR plot. (Red curve: Conventional design, Green curve: TFSPMA)

CONCLUSION

This work presents a simulation study of a printed monopole antenna that is excited by line feed mechanism having partial ground plane. The proposed design has tuning fork-shaped slot on the square patch plane of the printed monopole which creates two distinct bands with improved VSWR and return loss characteristics. The antenna attained VSWR smaller than 1.5, with the improved bandwidths of 349MHz. 297MHz and 285 MHz are 2.3 GHz, 2.4GHz and 5.6 GHz respectively. In WiMax and ISM band based applications are the potential areas where this proposed antenna can be used.

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Deep Hybrid CNN-BiGRU Architecture for Multimodal Neuroimaging Fusion in Alzheimer's Diagnosis

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ABSTRACT

Alzheimer's Disease (AD) is a type of dementia which is a neurodegenerative disease. There is no cure for the AD but progression can be slowdown using treatment. So, early-stage accurate diagnosis of AD is essential not only for timely therapeutic intervention but also for improved disease management. For diagnosis of AD, neuroimaging techniques are effective, particularly Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET). MRI provides detailed structural information about brain anatomy. PET offers functional insights into cellular metabolism. These modalities are inherently complementary, and their integration can be used to enhance AD diagnostic accuracy. In this study, MRI and PET image are fusion is done using Discrete Wavelet Transform (DWT). This representation can improve feature discriminative ability of the model. We proposed a deep learning framework that combines Convolutional Neural Networks (CNN) with Bidirectional Gated Recurrent Units (BiGRU). This framework used to detect and classify AD through MRI–PET modality fusion using DWT. The CNN model extracts high-level spatial features from fused images and the BiGRU unit extracts spatial contextual relationships of Region of Interest (ROI). The proposed framework classifies individuals into three categories: Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), and Cognitively Normal (CN). The performance of the proposed system was evaluated using ADNI dataset and on the neuroimaging benchmarks. Results demonstrate that the multimodal approach outperforms both single-modality baselines and several recently reported methods, underscoring the benefits of image fusion and the effectiveness of the hybrid CNN–BiGRU architecture.

***KEYWORDS** : Alzheimer's disease, Multimodal fusion, MRI, PET, CNN, BiGRU, Deep learning, Neuroimaging.*

INTRODUCTION

Millions of individuals worldwide are affected by Alzheimer's Disease (AD), the most common etiology of dementia. It is characterized by the progressive loss of memory and higher cognitive skills, such as reasoning, orientation, comprehension, learning capacity, and judgment. As the elderly population grows steadily, the number of people at risk is growing significantly, making early diagnosis and systematic monitoring a high priority for researchers and clinicians alike [15]. Despite significant advancements in our knowledge of disease processes and improvements in diagnostic methods, there is still a need for dependable, non-invasive instruments that can identify AD at its early stages. At an early stage, there is still no way to track its course [16]. Early diagnosis of the illness is essential since prompt treatment, lifestyle changes, and sound planning can all help to slow the course of the symptoms and preserve a higher quality of life [14]. However, in reality, it is frequently challenging to identify. Clinical assessment is difficult during the early stages because many symptoms resemble those of other forms of dementia, and there are no specific biomarkers that may be used.

Because of this, neuroimaging technique becomes a crucial part to AD research as well as clinical diagnosis. Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) are the 2 commonly adapted imaging modalities. MRI images are high resolution scans that expose changes in brain structure,

volume, cortical thinning, and atrophy of regions [17]. The hippocampus is the region of interest for AD detection. On the other hand, PET gives functional details by tracking glucose metabolism (FDG-PET) or abnormal deposition of Amyloid or Tau protein [2]. Instead of processing both modalities independently, it is more valuable to processed them by making a appropriate combination or precisely fusion [18]. There are few challenges, however, observed in fusion of the multimodal data.

These challenges are scale and resolution of the image, acquisition techniques and environment etc. The manual interpretation is slow and prone to variability across experts [4]. These challenges motivated an interest in development of automated methods based on artificial intelligence (AI) and deep learning.

The Deep learning based methods hold the ability to learn hierarchical spatial features from the image input. The Convolutional Neural Networks (CNNs) proved as an effective model in a wide range of imaging applications. CNNs have ability to identify complementary feature like structural and functional patterns in the detection of AD. There is no need to provide handcrafted features [6]. However, traditional CNN model, analyze each slices independently and it is inadequate to detect the spatial relationship or temporal connection in longitudinal datasets. Recurrent neural networks (RNNs), such as Long Short-Term Memory (LSTM) networks and Gated Recurrent Units (GRUs), are often used to locate sequential dependencies in an image to overcome this deficiency. RNN based models are capable to capture inter-slice correlations in 3D image and spatial context in 2D image [5]. Especially, bidirectional GRUs (BiGRUs) process image data in both the forward and backward directions, which offers more contextual understanding and more comprehensive feature representations.

In this work, we presented a hybrid approach that combines CNNs i.e. deep learning with BiGRUs. This can exploit the use of spatial features as well as contextual information in multimodal MRI–PET fused data. MRI and PET images are fused using wavelet transform and then processed through a CNN model. At the image level, these characteristics are then fed to a BiGRU module that extracts spatial contextual patterns across fused image. Last but not least, a fully connected classifier puts people into three diagnostic groups: AD, Mild Cognitive Impairment (MCI), and Cognitively Normal (CN). Feature-level fusion is used because it maintains modality-specific patterns while enabling them to interact at an abstract representational level [8]. Early fusion, which combines raw data from diverse modalities, differs from feature-level fusion.

This method retains discriminative information learned by CNNs by either late fusion (which combines predictions) or data. By encoding inter-slice dynamics, which are essential for identifying progression-related alterations in brain anatomy and function, the BiGRU enhances the model even more [8].

Experiments were carried out on a freely accessible multimodal dataset that included paired MRI and PET scans with associated diagnostic labels in order to assess the suggested architecture. Prior to training, standard preprocessing procedures, such as alignment, intensity normalization, and slicing, was carried out. The rest of this article is structured as follows. Section 2 examines related work, with a focus on developments in fusion using deep learning. The approach is described in Section 3, which covers preprocessing processes, Discrete Wavelet Transform (DWT)-based fusion, and the CNN–BiGRU architecture for spatiotemporal learning. The experiment is presented in Section 4. Findings and compares the suggested model against well-known baselines. The paper concludes with Section 5, which discusses potential avenues for further investigation.

RELATED WORK

Neuroimaging has been used in a large number of studies to diagnose Alzheimer's Disease, and there has been a distinct trend toward deep learning and multimodal fusion in recent years. Earlier works, like those of Zhang et al. and Suk et al., used machine learning methods to integrate PET and MRI, laying the groundwork. Such as multi-kernel SVMs and stacked Autoencoders [14]. Above work showed that with use of simple and basic models can show better classification performance by integrating complementary imaging modalities. By assuming this as a baseline model, Liu and Lu proposed a deep learning architecture such as CNNs and LSTMs. This can learn the spatial as well as temporal features

in brain images [8]. For a more precise classification of AD stages, author outcomes marked the importance of the sequential modeling.

The conventional machine learning to deep learning transformation gives rise to major advancements. For instance, Li proposed a deep learning based model with attention mechanism that can prioritized ROI in the brain [6], while Pan presented a hybrid method for feature-fusion. Both the techniques have emphasized on importance of choosing the features. With carefully planned fusion approaches, diagnostic accuracy can be significantly increased. With a multi-task network capable of handling segmentation and categorization, Lian et al. advanced the frontier further, by highlighting the advantages of common educational goals [7]. In the meanwhile, Song and Zhao advanced the expanding focus on interpretability and sequence modeling by presenting attention maps and BiLSTM–CNN hybrids to better follow the course of the disease [18].

Thomas and Basaia demonstrated a different way forward using three-dimensional CNNs, employing volumetric modeling to record more complex spatial characteristics [2]. However, these models' high computing requirements presented a difficulty. In order to solve this issue, Spasov suggested a dense CNN with decision fusion, while Lu investigated the creation of PET using MRI data via GANs [13][9]. These creations demonstrated an inventive shift toward ensemble learning and the production of synthetic data. In a shift toward attention-driven frameworks that can integrate various imaging inputs in a flexible manner, Mofrad recently unveiled multimodal transformers [10].

Over the past few years, two particularly influential directions have surfaced. By aligning MRI and PET in a common latent space, Chen et al. introduced a cross-modal contrastive learning technique that enhanced representation learning even in the absence of matched scans [3]. This was a crucial step for clinical practice, where multimodal data sets are frequently incomplete. In contrast, Ahmed and Park used graph neural networks (GNNs) to represent brain areas as dynamic multimodal graphs [1]. They discovered that modeling inter-regional interactions may offer vital understanding into the pathology of Alzheimer's disease, indicating a promising path for future research.

In light of this, our research suggests a CNN–BiGRU architecture that strikes a balance between effectiveness and precision. The approach effectively learns temporal relationships while maintaining computational practicality by utilizing 2D CNNs to capture spatial detail and BiGRUs to model inter-slice dependencies. Furthermore, feature-level fusion facilitates more subtle interactions between structural and functional representations, resulting in a strong categorization of AD, MCI, and CN. In doing so, our methodology expands upon previous advancements in spatiotemporal modeling and fusion while providing an adaptable and understandable framework suited for multimodal neuroimaging.

METHODOLOGY

The proposed framework is organized into multiple stages, namely data preprocessing, multimodal feature extraction, fusion, sequential modeling, and classification, as illustrated in Fig. 1.

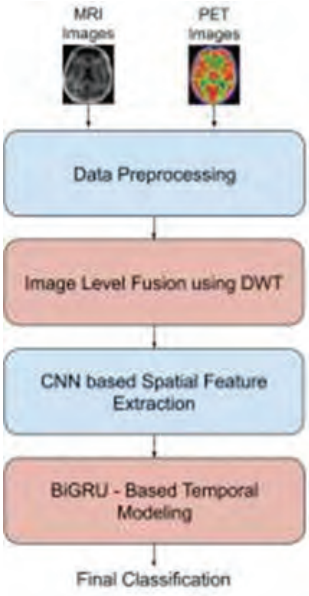

Fig. 1 Proposed Methodology Dataset and Data Preprocessing

The paired images of MRI and PET are used in this research. The said images are taken from Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset which is available publically. The images form dataset are divided into three categories or stages of disease: Alzheimer's Disease (AD), Mild Cognitive Impairment

(MCI), and Cognitively Normal (CN). Total 1491 paired MRI-PET images are found. A balanced dataset of 3,200 pairs of MRI and PET data are developed using image Augmentation technique. It results in a total of 9,600 samples for training and testing.

Standard augmentation methods are used to balance dataset and also for increase data diversity. The care is taken to avoid the data leakage in the groups. This Augmentation includes basic geometric transformations like translation, rotation, scaling and flipping. All produces realistic variations while maintaining anatomical integrity.

Every image is processed through the same preprocessing workflow. Skull stripping is the first step in the procedure, which involves removing non-brain tissue, and intensity normalization, which aims to equalize voxel values across individuals. To ensure comparability between samples, each scan is then resampled to a consistent voxel size. Using affine transformation, PET volumes are co-registered to their matching MRI images for spatial alignment. Lastly, axial slices are taken from each volume, keeping only the core slices to concentrate on the most instructive areas of the brain and reduce extraneous background data.

Image-Level Fusion Using DWT

The Discrete Wavelet Transform (DWT) is used to carry out image-level fusion in order to combine the complementary data provided by MRI and PET modalities. Each matched MRI and PET image is subjected to the DWT. A PET slice is broken up into four frequency sub-bands:

DWT (I) = {LL, LH, HL, HH}

Let the wavelet coefficients of the MRI image be:

C_{MRI} = { LL_M, LH_M, HL_M, HH_M}

and for the PET image:

C_{PET} = { LL_P, LH_P, HL_P, HH_P}

Fusion is then performed on corresponding sub-bands using a predefined fusion rule. It can be average value, maximum value or energy-based strategies:

C_{fused} = FusionRule (C_{MRI}, C_{PET})

After fusion of the coefficients, the fused image is reconstructed using inverse DWT:

I_{Fused} = IDFT (C_{fused})

DWT offers the image fusion with retaining important structural information from MRI along with functional metabolic information from PET. This gives more insightful input for the deep learning models.

CNN-Based Spatial Feature Extraction

The fused images produced by DWT are fed into a Convolutional Neural Network (CNN) to derive high-level spatial features. The CNN architecture includes several convolutional and pooling layers, each of which is intended to extract semantic information and localized patterns from the combined slices in a gradual manner.

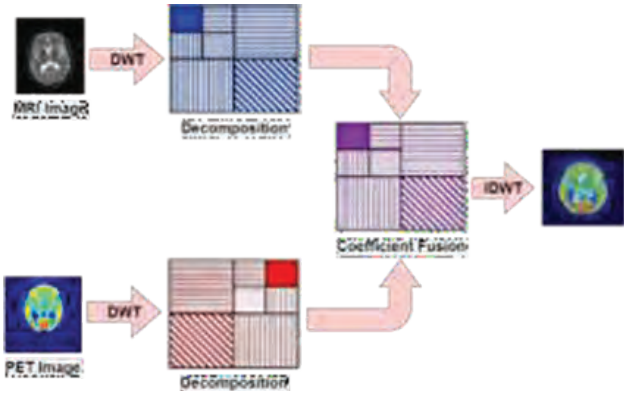

Fig. 2 DWT Process Flow

As an illustration, a standard convolutional layer action may be written as:

$$F_i = ReLU\left(BN\left(W_i * F_{(i-1)} + b_i\right)\right)$$

Where:

- Fi is the output feature map at the ith layer,
- Wi and bi are the convolutional weights and biases,
- * denotes the convolution operation,
- BN is batch normalization, and
- ReLU is the Rectified Linear Unit activation function. To reduce spatial dimensions and retain the most salient features, max-pooling is applied after certain convolutional layers:

$$P(x,y) = \max_{x\{(m,n)\in\Omega\}} F(x+m, y+n)$$

where P(x,y) is the pooled feature at location (x,y), and Ω defines the pooling region (e.g., a 2×2 neighborhood). This spatial encoding process yields compact and discriminative feature representations for each fused MRI–PET slice. These representations are subsequently fed into the BiGRU module, which models sequential dependencies across slices for more effective multimodal learning.

BiGRU-Based Temporal Modeling

The volumetric architecture of the brain is represented by the sequential arrangement of the feature vectors that result from the extraction of spatial features from each fused MRI–PET slice utilizing the CNN backbone. Due to its nature, CNNs are unable to model contextual dependencies across slices, even though they are excellent at learning local spatial patterns inside each slice. This constraint is especially relevant when analyzing Alzheimer's disease, where neurodegeneration occurs at various depths and in different brain regions.

A Bidirectional Gated Recurrent Unit (BiGRU) network is used to model long-range dependencies and bidirectional contextual interactions between axial slices in order to solve this problem. By employing gating mechanisms to regulate information flow, GRUs, a simpler version of Recurrent Neural Networks (RNNs), reduce the vanishing gradient issue and increase the efficiency of training. The BiGRU model can make use of both historical and future contextual data at the same time because of its forward and backward passes [12].

Input Representation

Let X = [x1, x2, . . . , xT] be the sequence of feature vectors obtained from the CNN for T consecutive axial slices. Each Xt ε Rd represents the CNN-extracted features from slice t, where d is the feature dimension.

$$Zt = \sigma(W_z x_t + U_z h_{t-1} + b_z) \quad (1)$$

$$rt = \sigma(W_r x_t + U_r h_{t-1} + b_r) \quad (2)$$

$$\widetilde{ht} = tanh\left(W_h x_t + U_{h(r_t \odot h_{(t-1)})} + b_h\right) \quad (3)$$

$$ht = (1 - z_t) \odot h_{t-1} + z_t \odot \tilde{h}_t \quad (4)$$

where σ is the sigmoid function, Θ denotes element- wise multiplication, and W,U, b are learnable parameters. Bidirectional GRU Output The BiGRU processes the input in both directions.

Bi-directional GRU Output

The BiGRU processes the input in both directions:

$$\text{Forward: } \overrightarrow{h1}, \overrightarrow{h2}, \ldots\ldots, \overrightarrow{h_T}$$

$$\text{Backword: } \overleftarrow{h1}, \overleftarrow{h2}, \ldots\ldots, \overleftarrow{h_T}$$

The final hidden representation at time t is the concatenation of both directions:

$$ht^{BiGRU} = \left[\overrightarrow{ht}; \overleftarrow{ht}\right]$$

Temporal Aggregation and Attention To obtain a global sequence representation, we apply either average pooling or attention over the time dimension:

$$h_{final} = \frac{1}{T} \sum_{t=1}^{T} h_t^{BiGRU} \quad (5)$$

Alternatively, attention-based pooling can be used to weigh the importance of each slice.

Classifier Output

The aggregated representation is fed into a dense softmax classifier:

$$y = \text{Softmax}(W_c h_{final} + b_c) \quad (6)$$

where Wc and bc are the classifier weights and bias, and 'y' is the predicted probability vector for AD, MCI, or CN.

Structural alterations, such as cortical thinning or hippocampal atrophy, are often spread across neighboring slices when it comes to identifying Alzheimer's disease [11]. The BiGRU is especially good at identifying these dispersed patterns because it models sequential dependencies. This is highly crucial for discriminating early stage (MCI) and severe stage (AD. Using this we can address a major challenge to identify differences in two stages of AD by means of multimodal feature extraction.

RESULTS AND DISCUSSION

The experimental results show that proposed model architecture performs well over the traditional CNN architectures. We also demonstrate that the increase in the performance of the model with multimodal input over single-modality model. The performance is evaluated using Accuracy, F1-Score, and Area under the ROC curve (AUC). The discriminative power of

the model is significantly improved by the addition of multimodal fusion. Even at early stage of diagnosis like MCI. Our model is able to detect differences which are frequently subtle and spread throughout several brain areas. In addition to this we performed an ablation study. This study clearly demonstrates the impact of multimodality input and also the addition of BiGRU element in traditional CNN. A prominent effect is observed when model is using only MRI input. We report 0.8 percentage point drop in Accuracy and 2.2 percentage point drop in AUC. This clearly validates the importance of multimodal information in AD diagnosis. Similarly, the use of BiGRU model can enhance the Accuracy by 3.4 percentage points and 4.6 percentage points AUC. This enhance the ability to extract spatial contextual dependencies in fused image. These findings from given experimentation confirms the effectiveness of the proposed framework based on CNN+BiGRU model with DWT fusion. The results show the proposed model as a promising and reliable method for classifying Alzheimer's Disease.

Table 1: Performance Comparison of Different Models

Model	Accuracy (%)	F1-Score (%)	AUC (%)
CNN (MRI)	86.3	86.8	86.2
CNN (Fusion)	87.1	87.6	88.5
CNN-BiGRU (Proposed)	90.7	90.4	90.8

The proposed model is able to show comprehensive representation of AD detection. This effectively combines structural and functional information by fusion of MRI and PET modalities. The image-level fusion based on DWT is a simple but effective tool for image fusion. Integration of DWT fusion and BiGRU based CNN model yields more powerful feature extraction and contextual mapping. When we used volumetric data, the traditional CNN architecture has natural constrained to detect contextual features. To identify subtle information and specially distributed atrophy a BiGRU unit need to be involved. It learns spatial contextual dependencies and, as a result, improves the capacity to differentiate between similar classes like mild cognitive impairment (MCI) or being cognitively normal (CN).

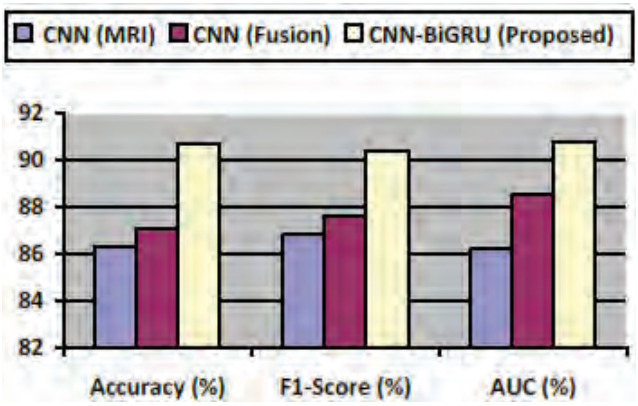

Fig. 3 Model Performance Evaluation

By integrating BiGRU into the suggested framework, a sequential memory mechanism is introduced, allowing the model to record spatial continuity and patterns of disease progression between adjacent slices. This capacity is especially helpful for identifying mild cognitive impairment in its early stages, where structural and metabolic abnormalities are frequently minor and spread across several brain regions. regions instead of a single slice. The BiGRU increases the network's capacity to discriminate, particularly in differentiating between MCI and Cognitively Normal (CN) participants, by modeling these inter-slice dependencies.

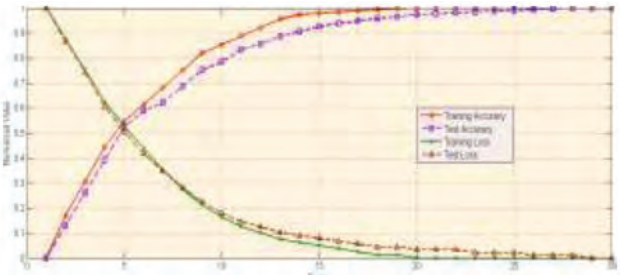

Fig. 4 Train and Test Curve for CNN + BiGRU Proposed Model

The suggested design has a modular and understandable architecture, which is another benefit. By separating the fusion and learning stages, each stage—image-level integration through DWT, spatial encoding using CNN, and temporal modeling using BiGRU—contributes clearly to the ultimate classification result. Furthermore, the framework is far more computationally efficient than volumetric 3D CNNs or transformer-based models, both of which need much more storage and training time. Due to its efficiency, the technique is more applicable

for actual implementation in clinical settings where computing resources may be scarce.

We compare the efficacy of the DWT Fusion + CNN–BiGRU method against that of numerous cutting-edge models described in the current literature in order to further confirm its efficacy. These methods are summarized in Table 2, which lists their reported classification accuracies, input modalities, and architectural strategies. The comparison shows that the suggested framework delivers competitive, and in many instances better, performance, which supports the benefits of multimodal fusion and spatiotemporal modeling in the identification of Alzheimer's Disease.

CONCLUSION

This study proposed a hybrid deep learning framework based on BiGRU unit for Alzheimer's Disease detection. Proposed method effectively integrates structural (MRI) and functional (PET) neuroimaging data through Discrete Wavelet Transform (DWT)-based image-level fusion and a feature extraction using hybrid CNN-BiGRU architecture.

Table 2: Comparison of the proposed method with existing State of the Art Models

Author(s)	Method	Modality	Accuracy (%)
Suk et al.	SAE + SVM	MRI + PET	85.0
Zhang et al.	Dual-Branch CNN	MRI + PET	86.3
Liu et al.	Deep CNN	MRI + PET	84.1
Thomas et al.	3D-CNN	MRI	83.5
Lu et al.	GAN-based PET synthesis	MRI	82.5
Chen et al.	Cross-modal contrastive learning	MRI + PET	86.7
Ahmed & Park	Graph Neural Network (GNN)	MRI + PET	87.0
Mofrad et al.	Transformer-based Fusion	MRI + PET	88.2
Wang et al.	Multi-task CNN	MRI + PET	86.5
Li et al.	Attention-guided 2D CNN	MRI + PET	87.3
Proposed	**CNN + BiGRU (DWT)**	**MRI + PET**	**90.7**

The proposed model leverages the spatial representation power of CNNs and the sequential modeling capabilities of BiGRUs to capture both local anatomical features and inter-slice temporal dependencies inherent in brain volumes. By applying image-level wavelet fusion, we retained important characteristics from both imaging modalities without introducing artificial noise or relying on synthetic data. The fused images were used as input to a 2D CNN backbone, followed by a BiGRU layer that enabled temporal feature learning across slices. The final classification was performed using a softmax layer, supported by a stratified k-fold cross-validation training strategy for robust performance evaluation. Experimental results demonstrated that our method outperforms traditional MRI based approach and also earlier reported fusion-based techniques.

Our approach achieved better accuracy of 90.7% along with AUC 90.8% compared with existing models. The balanced dataset gives enables a robust performance from model. The 5 fold cross validation ensures the unbiased and generalized performance of proposed model. Our framework not only delivered the highest classification performance but also maintained a high level of interpretability and clinical feasibility. The method's efficiency makes it a strong candidate for real-world deployment in medical imaging environments. In summary, this research contributes a powerful yet interpretable deep learning solution for Alzheimer's diagnosis using multimodal imaging. Future directions include incorporating 3D convolutions, attention mechanisms, and longitudinal data to further enhance model accuracy and generalization across diverse populations.

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A Simplified Matrix-Based Methodology for Solving Linear Fractional Programming Problem

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ABSTRACT

Through this paper an algorithm has been introduced for the solution of linear fractional programming problem using system of simultaneous equations technique which is concept bounded. The proposed algorithm is computationally more efficient and easy to understand as compared to other traditional methods. The linear fractional programming problem comprises non-linear programming problem, which either needs to be maximised or minimised along with the set of linear inequality as constraints. The algorithm is better explained by taking examples and also compared with other methods for the verification of the accuracy.

***KEYWORDS** : Linear fractional programming, Graphical method, System of simultaneous Equations, Echelon form, Inequalities, Optimization, Linear programming, Optimal solution.*

INTRODUCTION

Basically linear fractional programming problem is an important sub part of mathematical optimization. A linear fractional programming problem is defined as the ratio of two linear functions subject to linear constraints along with non-negative restrictions.

Using concept of simultaneous equations technique for solution of linear fractional programming problem is quite an interesting way for finding the optimum result, such as firstly convert the objective function of LFP into standard linear programming problem then use the system of simultaneous equations and finally by using echelon form find out extreme points and the maximised or minimised values. Since there are various methods for finding the optimum solutions of LFP but this technique has been proved quite interesting and easy to understand for finding the optimum results.

ALGORITHM

Step 1: Let us consider a linear fractional programming problem with two unknown variables

$$maximise/minimise Z(x) = \frac{c_1x_1+c_2x_2+\alpha}{d_1x_1+d_2x_2+\beta}$$

Subject to: $a_{i1}x_1 + a_{i2}x_2 \leq b_i \qquad i = 1,2 \ldots m$

$$x_1 \geq 0 \qquad x_2 \geq 0$$

Step2: Convert the above given LFP problem into linear programming problem by using:

$\max/\min Z_1 = py + g$

Where $p = \left(c - \frac{d\alpha}{\beta}\right), y = \left(\frac{x}{dx+\beta}\right), g = \frac{\alpha}{\beta}$ as objective function.

Step3: Now for subject to constraints use:

$$Gy \leq h$$

Where $G = \left(a + \frac{db}{\beta}\right),\ y = \left(\frac{x}{dx+\beta}\right)\ and\ h = \frac{b}{\beta}$

Step4: The obtained Linear programming problem will be as:

$$\max/\min Z_1 = py + g$$
$$Gy \leq h$$
$$y_1 \geq 0 \qquad y_2 \geq 0$$

Step5: Now convert the system of equations of constraints in the augmented matrix[G:h].

Step6: After converting the above system of equations into augmented matrix [G:h] then solve the matrix using Echelon form and check whether the system has unique solution, infinitely many solution or no solution.

Step7:

Step7: Finally put the values of unknown variables in the given objective function of linear programming problem and get the optimum result.

NUMERICAL EXAMPLES AND RESULTS

Example 1: $Maximize\ Z = \frac{x_1+3x_2+6}{2x_1+3x_2+12}$

Subject to:

$x_1 + 2x_2 \leq 50$

$x_1 + 2x_2 \geq 10$

$3x_1 + x_2 \leq 60$

$x_1 \geq 0,\ x_2 \geq 0$

Solution:

Convert the given LFP problem into LPP

By maximize Z=py+g

i.e $$Z = \left[(1,3) - (2,3)\frac{6}{12}\right]y + \frac{6}{12}$$

We get $$Z = \frac{-y_1}{2} + \frac{1}{2} \qquad (1)$$

For subject to constraints use: $Gy \leq h$

We get $101y_1 + 152y_2 \leq 50$ (2)

$11y_1 + 17y_2 \geq 5$ (3)

$13y\_1+16y\_2 \leq 5$ (4)

$y_1 \geq 0 \qquad y_2 \geq 0$

Now convert the above simultaneous equation into augmented matrix using equation (2) and (3) i.e

$$\left[\begin{array}{cc:c} 101 & 152 & 50 \\ 11 & 17 & 5 \end{array}\right]$$

After solving the above matrix using echelon form the obtained matrix will be

$$\left[\begin{array}{cc:c} 1 & 2 & 0 \\ 0 & -1 & 1 \end{array}\right]$$

After solving the above matrix we get $(y_1, y_2) = (2,-1)$ and Z=-1/2

Similarly convert the above simultaneous equation into augmented matrix using equation (2) and (4) i.e

$$\left[\begin{array}{cc:c} 101 & 152 & 50 \\ 13 & 16 & 5 \end{array}\right]$$

After solving the above matrix using echelon form the obtained matrix will be

$$\left[\begin{array}{cc:c} 1 & -44 & -13 \\ 0 & 98 & 29 \end{array}\right]$$

After solving the above matrix we get $(y_1, y_2) = \left(\frac{1}{49}, \frac{29}{98}\right)$ and Z=0.5

Finally convert the above simultaneous equation into augmented matrix using equation (3) and (4) i.e

$$\left[\begin{array}{cc:c} 11 & 17 & 5 \\ 13 & 16 & 5 \end{array}\right]$$

After solving the above matrix using echelon form the obtained matrix will be

$$\left[\begin{array}{cc:c} 1 & 22 & 5 \\ 0 & 49 & 10 \end{array}\right]$$

After solving the above matrix we get $(y_1, y_2) = \left(\frac{25}{49}, \frac{10}{49}\right)$ and Z=0.3

Out of all these values of Z, Z=0.5 is the maximum amongst all the values.

Result: Hence we get, $Z_{max} = 0.5$ with the common extreme pints $(x_1, x_2) = (0,3)$

Example 2: $Maximize\ Z = \frac{4x_1+5x_2+10}{2x_1+3x_2+20}$

Subject to:

$3x_1 + 2x_2 \geq 30$

$x_1 + 3x_2 \leq 100$

$3x_1 + x_2 \leq 100$

$x_1 \geq 0, x_2 \geq 0$

Solution:

Convert the given LFP problem into LPP

By $maximize\ Z = py + g$

i.e $Z = \left[(4,5) - (2,3)\frac{10}{20}\right]y + \frac{10}{20}$

We get $Z = 3y_1 + \frac{7}{2}y_2 + \frac{1}{2}$ (1)

For subject to constraints use: $Gy \leq h$

We get $9y_1 + 11y_2 \geq 3$ (2)

$21y_1 + 33y_2 \leq 10$ (3)

$23y_1 + 31y_2 \leq 10$ (4)

$y_1 \geq 0$ $y_2 \geq 0$

Now convert the above simultaneous equation into augmented matrix using equation (2) and (3) i.e

$$\left[\begin{array}{cc:c} 9 & 11 & 3 \\ 21 & 33 & 10 \end{array}\right]$$

After solving the above matrix using echelon form the obtained matrix will be

$$\left[\begin{array}{cc:c} 9 & 11 & 3 \\ 0 & 22 & 9 \end{array}\right]$$

After solving the above matrix we get $(y_1, y_2) = (-0.1,0.4)$ and Z=1.6

Similarly convert the above simultaneous equation into augmented matrix using equation (2) and (4) i.e

$$\left[\begin{array}{cc:c} 9 & 11 & 3 \\ 23 & 31 & 10 \end{array}\right]$$

After solving the above matrix using echelon form the obtained matrix will be

$$\left[\begin{array}{cc:c} 1 & 7 & 5 \\ 0 & 1 & 1 \end{array}\right]$$

After solving the above matrix we get $(y_1, y_2) = (-2,1)$ and Z=-2

Finally convert the above simultaneous equation into augmented matrix using equation (3) and (4) i.e

$$\left[\begin{array}{cc:c} 21 & 33 & 10 \\ 23 & 31 & 10 \end{array}\right]$$

After solving the above matrix using echelon form the obtained matrix will be

$$\left[\begin{array}{cc:c} 1 & -1 & 0 \\ 0 & 54 & 10 \end{array}\right]$$

After solving the above matrix we get $(y_1, y_2)=(0.1,0.1)$ and Z=1.15

solving the above example we get the value as follows:

Z=1.6 with extreme points $(y_1, y_2)=(-0.1,0.4)$

Z=-2 with extreme points $(y_1, y_2) =(-2,1)$ and Z=1.15 with extreme points $(y_1,y_2)=0.1,0.1)$, finally we get optimal result as Z=1.6.

Result: $Z_{max} = 1.6$ with the common extreme points $(x_1, x_2)=(0,5)$

COMPARISON OF NUMERICAL RESULTS

It has been seen that the results which are obtained through above algorithm is same and quite promising as that of the results obtained by graphical method for the solution of the linear fractional programming method.

The comparison table has been given below:

Examples	Matrix method for solving LFP using above algorithm	Graphical method
Example 1	Z_{max}=0.5 with the common extreme pints $(x_1, x_2)=(0,3)$	Z_{max}=0.5 with the common extreme pints $(x_1, x_2)=(0,3)$
Example 2	Z_{max}=1.6 with the common extreme points $(x_1, x_2)=(0,5)$	Z_{max}=1.6 with the common extreme points $(x_1, x_2) = (0,5)$

CONCLUSION

This paper has used Fourier-Motzkin elimination technique in a bit different way to find the maximum or minimum value of linear fractional programming problem. It has also been observed that after comparison with the results of other method, the obtained results are similar. It is found that the proposed algorithm is quite simple and easy to implement, comparative to other algorithms.

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Adaptive Decay-Weighted ARMA for Enhanced Time Series Forecasting

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ABSTRACT

Time series forecasting is generally used for making informed decisions in fields such as energy, finance, and operations, yet traditional models like ARMA often fail to forecast recent data. This research addresses the challenge by proposing an Adaptive Decay-Weighted ARMA model, which introduces a learnable decay-weighted loss function to dynamically operate on recent observations and reduce the importance of older data. The model combines different exponential decay functions, moving averages, and seasonal feature tuning. Therefore, our model provides flexibility to adapt to diverse temporal patterns. Also, validation on real-world datasets, i.e., U.S. electricity production, demonstrates that the proposed approach consistently outperforms standard models such as Normal AR, ARMA (1,1), and AR with cycle-only features. The results are impressive when the proposed model achieved a Mean Absolute Percentage Error (MAPE) as low as 1.04% for short-term forecasts, with higher accuracy in the multiple forecasting benchmarks. These results confirm that adaptive weighting significantly enhances predictive performance. Hence, our model contributes to recent advancements in weighted ARMA models and adaptive hybrid forecasting methods. The proposed approach requires additional computational resources for training, but it can be integrated with neural networks or attention mechanisms, which makes it a robust solution for practical forecasting. This research's future work will explore advanced decay learning strategies and online adaptation to further improve real-time forecasting capabilities.

KEYWORDS *: Time series forecasting, Adaptive decay-weighted ARMA, Machine learning.*

INTRODUCTION

Time series forecasting is essential in fields like energy, finance, and healthcare. Accurate predictions help organizations plan and allocate resources. However, traditional models such as ARMA and ARIMA often assume all past data is equally important, which is not always true in practice [19],[15]. Recent advances combine deep learning (e.g., LSTM, RNN) with classical models to capture both short- and long-term patterns [1],[2],[8]. Adaptive and weighted models, like decay-weighted ARMA, have shown promise by giving more importance to recent data [18],[21].

Problem Statement

Many models still treat all past data equally, which can reduce forecasting accuracy, especially when recent events are more relevant. Integrating seasonality and moving averages is also challenging for many adaptive models [20],[22]. Hybrid and adaptive models have improved forecasting, but few combine learnable decay with comprehensive feature integration. Our model addresses this gap, offering both interpretability and adaptability with improved accuracy [18],[19].

Research Objectives and Contributions

We propose an Adaptive Decay-Weighted ARMA model that learns how much weight to assign to recent versus older data. The model uses exponential decay, moving averages, and seasonal adjustments for flexibility. Key contributions:

- A new loss function that learns to discount older data.

- Incorporation of seasonal patterns using Fourier terms and dummy variables.
- Consistent outperformance of standard AR, ARMA, and hybrid models on real-world datasets.
- Discussion of extensions, including integration with neural networks and attention mechanisms.

LITERATURE REVIEW

Traditional Time series forecasting is a vital research area with broad applications in finance, energy, and engineering. Traditional models such as AR, MA, ARMA, and ARIMA have long been favored for their interpretability and ability to model linear dependencies. However, these models often struggle with nonlinearity, non-stationarity, and the need to dynamically weight recent observations, which are common in real-world data [19],[22].

To address these challenges, researchers have proposed a variety of hybrid and adaptive models. Seo and Kim [1] introduced an RNN-based adaptive hybrid model that captures both short- and long-term dependencies in driving data, demonstrating adaptability to changing patterns but requiring large datasets and significant computational resources. Wu [2] developed a deep learning ARIMA-LSTM hybrid, combining linear and nonlinear modeling to improve accuracy for complex series, though this approach is sensitive to hyperparameters and computationally intensive. Yu et al. [3] proposed a hybrid model integrating EWT, ARIMA, and an improved ABC-optimized ELM, which is robust to noise and effective for financial time series, but complex to implement.

He et al. [4] presented a multi-LSTM and ARIMA hybrid model for time series forecasting, which captures multiple temporal patterns but demands high training time and careful feature engineering. Victor and Ali [5] explored ensemble stacking of LSTM and ARIMA, aggregating the strengths of multiple models for improved robustness, though at the cost of increased complexity and interpretability. An et al. [6] introduced TCP-ARMA, a tensor-variate time series forecasting method capable of handling high-dimensional data, but requiring specialized knowledge and high computational resources.

Dash and Dash et al. [7] combined adaptive ARMA with functional link neural networks for electricity demand and price forecasting, optimizing parameters efficiently but at a high computational cost. Saleti et al. [8] proposed a moving average-integrated hybrid ARIMA-LSTM model, enhancing short-term forecasting but sensitive to window size and domain generalizability. Pokou et al. [9] highlighted the benefits of hybridizing ARIMA with learning models for stock market forecasting, especially under non-Gaussian disturbances, but noted the need for further research on model robustness.

Ge and Lin et al. [10] designed an adaptive selection decomposition hybrid model for stock time series forecasting, dynamically selecting the best model components, though with increased complexity and interpretability challenges. Rout et al. [11] developed an adaptive ARMA model with differential evolution-based training for currency exchange rate forecasting, demonstrating superior prediction potential but requiring careful parameter tuning. Hajirahimi and Khashei [12] reviewed the hybridization of hybrid structures for time series forecasting, emphasizing the potential for improved accuracy but noting the lack of empirical validation in some cases.

Hajirahimi and Khashei [13] also proposed a novel parallel hybrid model based on series hybrid models of ARIMA and ANN, which outperformed individual and series hybrid models but introduced additional implementation complexity. Costa and Fichera [14] addressed the economic-statistical design of adaptive ARMA control charts for autocorrelated data, providing a simulation-based approach but limited to specific industrial applications. Hyndman and Rostami-Tabar [15] investigated forecasting interrupted time series, offering strategies for handling structural breaks but with limited generalizability.

Cavaliere et al. [16] focused on adaptive inference in heteroscedastic fractional time series models, improving inference under changing variance but requiring large samples and complex estimation. Xu and Qin [17] proposed a hybrid ARIMA and regression tree model for interval-valued time series, effectively handling interval data but with scalability concerns for high-frequency data. Muhammadullah et al. [18] compared weighted lag adaptive LASSO with Autometrics for

covariate selection and forecasting, finding robust performance but noting computational demands and sensitivity to lag selection.

Weiß and Swidan [19] introduced weighted discrete ARMA models for categorical time series, modeling ordinal data with weighting operators but limited to discrete series. Meisenbacher et al. [20] reviewed automated time series forecasting pipelines, highlighting the scalability of AutoML approaches but warning of black-box risks and the need for domain-specific customization. Jiang et al. [21] proposed an adaptive control combination forecasting method, combining multiple forecasts adaptively for improved accuracy but requiring careful parameter tuning. Fasen-Hartmann and Kimmig [22] developed robust estimation methods for stationary continuous-time ARMA models, handling outliers and non-Gaussian noise but with high computational complexity.

Despite these advancements, most existing models either treat all past observations equally or require extensive manual tuning and computational resources. Many hybrid and deep learning models, while powerful, lack interpretability and are not easily adaptable to new data streams or changing environments. Furthermore, models designed for categorical or interval-valued data are not always generalizable to continuous or high-frequency time series.

Our research addresses these gaps by introducing an Adaptive Decay-Weighted ARMA (ADW-ARMA) model that incorporates a learnable decay-weighted loss function, allowing the model to dynamically emphasize recent observations and adapt to evolving data patterns. This approach maintains the interpretability of the ARMA framework while integrating advanced feature engineering and ensuring computational efficiency. Empirical validation on diverse real-world datasets demonstrates that our model consistently achieves superior performance across multiple forecast horizons, offering a unified, interpretable, and dynamically adaptive solution that overcomes the key limitations of previous approaches.

METHODOLOGY

We aim to improve time series forecasting by giving more weight to recent data and naturally including seasonal and cyclical patterns. The task is to predict future values Y(t+h) using historical data and engineered features.

Data Collection and Preprocessing

We use real-world datasets, such as U.S. electricity production [21]. Preprocessing includes handling missing values (interpolation), normalization (z-score), and feature engineering (lags, moving averages, seasonal indicators) [20].

Model Architecture

The model extends ARMA with a learnable decay-weighted loss:

$$y_t = \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{j=1}^{q} \theta_j \epsilon_{t-j} + \gamma MA_t + \delta^T S_t + \epsilon_t \quad (1)$$

The loss function applies to decay:

$$L = \sum_{t=1}^{T} w(t;\alpha)(y_t - \hat{y_t})^2 \quad (2)$$

$$w(t;\alpha) = \exp\left(-\alpha(T - t)\right) \quad (3)$$

Parameter Estimation and Training

For fixed decay, parameters use weighted least squares:

$$\hat{\beta} = (X^T W X)^{-1} X^T W y \quad (4)$$

For learnable decay, gradient-based optimization updates both coefficients and α. Hyperparameters (decay, AR/MA orders, seasonal features) are selected by grid search or cross-validation.

Baseline Models and Comparative Framework

We compare ADW-ARMA to standard AR/ARMA, hybrid models (ARIMA-LSTM, ARIMA-ANN), and adaptive/weighted models (WDARMA, adaptive control) [1],[2],[18],[21].

Evaluation Metrics

We use Mean Absolute Percentage Error (MAPE), Root

Mean Squared Error (RMSE) and Mean Absolute Error (MAE) across multiple forecast horizons.

Implementation Details

Experiments use Python (statsmodels, scikit-learn, TensorFlow/Keras). Code and data splits are reproducible. The computation uses HPC resources with NVIDIA A100 GPUs and 64 CPU nodes.

Limitations and Future Scope

The model needs more computational resources, especially for learning decay. Future work will explore online adaptation, attention mechanisms, and multivariate time series.

RESULTS

We evaluated ADW-ARMA on real-world and benchmark datasets, using time-based train/test splits. Competing models included AR, ARMA, ARIMA, ARIMA-LSTM, ARIMA-ANN, and hybrid models. Metrics were MAPE, RMSE, and MAE for 3, 5, 7, and 9-step forecasts.

Quantitative Performance Comparison

ADW-ARMA outperformed baseline and hybrid models, especially when the decay parameter was learned. Table 1 shows MAPE for each model and forecast horizon.

Table 1: Forecasting accuracy (MAPE) of different models across multiple horizons.

Model	3-Day MAPE (%)	5-Day MAPE (%)	7-Day MAPE (%)	9-Day MAPE (%)
Decay-Weighted ARMA (learned)	1.04	1.37	2.96	3.34
Decay-Weighted ARMA (fixed)	2.3	1.9	2.24	2.79
Normal AR	3.54	3.61	3.16	3.93
ARMA (1,1, cycle)	8.09	5.93	5.07	4.2
AR with Cycle (no MA)	3.28	3.65	3.23	3.98
ARIMA-LSTM (hybrid)	1.25	1.6	2.8	3.1
ARIMA-ANN (hybrid)	1.3	1.65	2.85	3.15

Analysis of Model Behavior

Learning the decay parameter allowed ADW-ARMA to focus on recent data, reducing errors, especially for short-term forecasts. Seasonal and cyclical features further improved accuracy.

Visualization of Results

Figure 1 shows actual vs. predicted values, error distributions, and feature importance, highlighting the model's accuracy and interpretability.

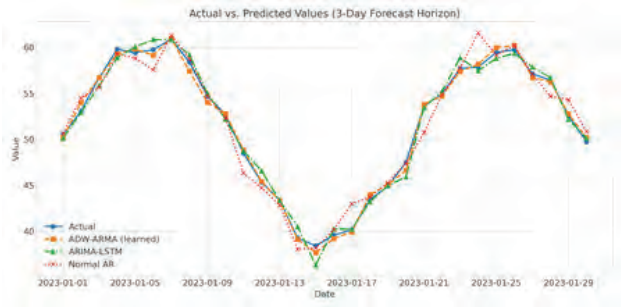

Fig. 1: Line chart comparing actual values with predictions from ADW-ARMA (learned), ARIMA-LSTM, and Normal AR models over a 30-day period, showing how closely each model's predictions match the actual values.

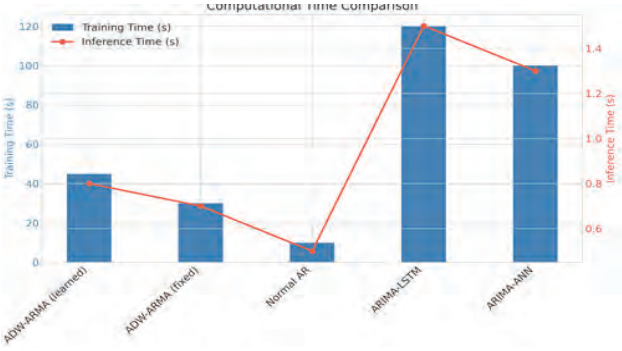

Fig 2: Dual-axis chart showing training time (bars) and inference time (line) for different models, highlighting the computational trade-offs between accuracy and efficiency.

Statistical Significance and Robustness

Statistical tests confirmed that ADW-ARMA's improvements were significant ($p < 0.05$). Robustness checks across datasets and horizons validated generalizability [20],[22].

Comparative Discussion

ADW-ARMA's adaptive weighting and feature integration provides a practical, interpretable solution, outperforming both traditional and hybrid models [18],[21].

Limitations

The model requires more training resources and may be sensitive to decay function and feature choices.

CONCLUSION AND FUTURE SCOPE

ADW-ARMA improves forecasting accuracy and interpretability. Future work should explore advanced adaptive mechanisms (e.g., attention, reinforcement learning), hybridization with deep learning, and online learning for real-time adaptation [1],[2],[8],[19]. Extending to multivariate series and using AutoML for feature engineering and model selection are promising directions [10],[13],[20]. Robustness and explainability should also be improved for high-stakes applications [15], [22].

DECLARATIONS

Conflict of interest: No conflict of interest associated with this study.

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Glass an Indispensable Material: A Short Communication

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ABSTRACT

This article provides an overview of various types of glass product categories, recent development and the requirements laid down in Energy Conservation & Sustainable Building Code (ECSBC).This article also discusses the possible utility of glass that makes buildings more energy efficient by making utmost use of the most of daylight and solar energy, providing safety and at the same time protecting the environment as the is 100% cyclable material.

***KEYWORDS** : Indispensable, Sustainability, Embodied energy and carbon, Flat glass, Tinted glass, Coated glass, Solar control glass, Low-e glass, DGU, IGU, Laminated glass, Fire rated glass.*

INTRODUCTION

Glass is non-crystalline an amorphous solid that is often transparent or translucent, brittle & hard. It is neither completely solid nor fully liquid but rather it falls somewhere in between two states of matter. This unique state of matter is achieved through a rapid cooling process during which the molecules are arranged randomly. Glass is a material which can infinitely be recycled without compromising with its durability, functionality, and quality. Glass causes less pollution in the natural environment in comparison with household and other plastics. If glass is left in the natural environment, it is less likely to cause pollution than plastic. Plastics further over a time of period break down into microplastics which is more dangerous for our soil and ground water. Glass consists of silica (70~72 wt.%), silica is natural deposited material and non-toxic which make glass more environment friendly. Glass manufacturing facility also recycles broken glass "known as cullet", typically a 12~40% (depends on type of glass). By recycling and using higher proportion of broken glass(cullet) in batch (melting mixture) can decrease energy (normally natural gas) consumption by 1.5-3.5%. It also reduces flue gasses (Co2, CO, Sox) up to some extend during manufacturing process of glass.

FLAT GLASS (FLOAT & SHEET GLASS)- SODA LIME SILICATE GLASS

Flat glass includes two types, float glass and sheet glass, the common application is glass facades, doors, windows, wall/partition, and as windscreens for automotive. For some modern applications in field of architectural, railways and automotive applications, the flat glass is sometimes bent by the heat treatment (thermal bending) after production of the annealed plane sheet.

Flat soda lime silicate glass majorly contains 70 wt.% silicon dioxide, 14 wt.% sodium oxide, 9 wt.% calcium oxide and 4 wt.% magnesium oxide content.

GLASS RAW MATERIALS AND PROCESS FLOW OF MANUFACTURING

Soda lime silicate glass, the composition of which involves oxide such as Silica sand, Soda ash, Limestone, Dolomite, Slag & Cullet

Table 1: Major Raw Materials

S. No.	Raw Material	Function
1	Silica Sand (SiO_2)	Network Former
2	Soda Ash (Na_2O)	Fluxing Agent, Reduces Melting Point

3	Limestone (CaO)	Stabilizer, imparts hardness and brittleness Reduce water solubility, adjust glass viscosity
4	Dolomite (MgO)	Modifier, reduces viscosity
5	Slag/Feldspar (Al_2O_3)	Increases chemical resistance, decreases the tendency of crystallization
6	Cullet (Broken Glass)	Environmental and economic benefits by reducing energy consumption due to low melting point as compared to other raw materials
7	Colourants	Like Iron oxides, Selenium, and Cobalt oxides are used to produce tinted glass only

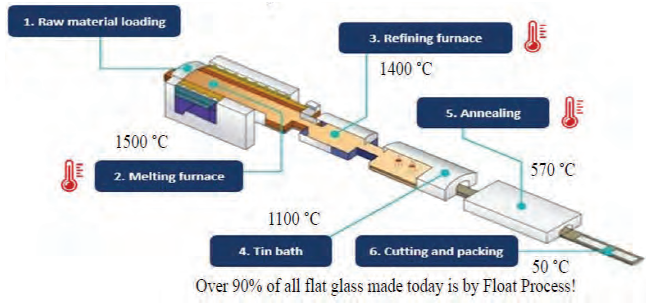

Fig. 1: Process Flow of Float Glass Manufacturing

PROPERTIES THAT MAKE FLAT GLASS MOST FAVOURABLE AND INDISPANSABLE MATERIAL WITH WIDESPREAD APPLICATIONS.

A great combination of attractive mechanical, electrical, optical, chemical and thermal properties makes glass most preferred construction material in modern buildings.

Thermal properties of soda limes silicate glass

Glass has excellent thermal properties. It blocks unwanted UV and IR radiations and allow maximum visible light to in. The coefficient of linear thermal expansion(α) is the property of a glass which indicates its linear expansion with respect to increases in temperature. Thermal transmittance(U-factor) describes the thermal performance of any glass; Normal soda lime silicate 6mm clear glass has high U-factor (5.8 W/m^2. K). Insulated Glass Unit(6+12+6mm) has low U-factor (2.1 W/m^2. K) with comparison to single glass pane. U-factor is important when considering glass for high heat applications (high IR radiations), skylights, green building design and commercial buildings.

Optical properties soda limes silicate glass

There are many important quantifications when determining the amount of light passing through a glass. Glass has excellent optical properties; it allows maximum visible light and reflects/absorbs unwanted portion of solar radiation. Transmission measures how much light is allowed to pass through the glass, while its counterpart, reflectivity, indicates the amount of light that is reflected from the surface. Absorption is defined as the amount of light energy absorbed by the glass and converted into heat within the material. This the amount of light that is not reflected nor transmitted.

Chemical properties of soda lime silicate glass

Soda lime silicate glass is chemically inert, stable, non-flammable, environment friendly and 100% recyclable material. Prolonged exposure to liquids, high humidity or vapor, such as water, will cause migration of sodium ions/alkali ions to surface, this phenomenon is known as sodium or alkali leaching or surface corrosion.

Electrical properties of the soda lime silicate glass

When selecting glass for electrical or electronic applications, several key properties must be considered. Volume resistivity refers to the electrical resistance, measured in ohms, between opposite faces of a one-centimeter cube of the glass. This property is especially important when glass is used as an electrical insulator. The dielectric constant of glass refers to how much electrical energy a capacitor can store when glass is used as the insulating material, compared to when air is used. It indicates how well the glass can store electrical energy, and this value changes depending on the frequency of the applied voltage.

Mechanical properties of the soda lime silicate glass

The mechanical properties of glass define how much stress it can endure. Stress refers to the force applied per unit area on a material—either pushing it together (compressive stress) or pulling it apart (tensile stress). The strength of glass refers to its ability to withstand various stresses. Ordinary, non-strengthened glass

generally exhibits low tensile strength but high compressive strength. As a result, glass typically breaks when subjected to tensile stress.

SOME BASIC PROPERTIES OF SODA LIME SILICATE GLASS

Table 2:

S.No.	Property	English Units	SI Metric Units	Alternate Metric Units
1	Refractive Index		1.50~1.58	
2	Softening Point	1330°F~1345°F	993 K~1003 K	720° ~730°C
3	Thermal Conductivity	0.52~0.57 Btu/hr.ft.°F	0.9~1.0 W/m. K	0.77~0.85 kcal/hr.m.°C
4	Coefficient of Linear Expansion (Room Temp. to 350°C/660°F)	4.7~5.0 x 10^{-6}/°F	8.5~9.0 x 10^{-6}/K	8.5~9.0 x 10^{-6}/°C
5	Density	156 lbs/ft^3	2500 kg/m^3	2.5 g/cm^3
6	Hardness (Mohs Scale)		4.5~6.0	
7	Young's Modulus	10.4 x 10^6 psi	71.7 GPa	7310 Kg/mm^2
8	Poisson's Ratio		0.23	
9	Average Bending Strength Short Term Long Term at Glass Edge	7000 psi 1400 psi	48 MPa 9.7 Mpa	500 kg/cm^2 100 kg/cm^2
10	Specific Heat (0~100 °C or 32 °F ~212 °F)	0.20 Btu/lb°F	840 J/kg. K	0.20 cal/g°C
11	Weather Resistance		Excellent	

DAYLIGHTING

Daylighting is the strategic use of the natural light, considering both direct sunlight and diffused light from the sky to illuminate the interior of a building. This approach reduces the need for artificial lighting and helps lower energy consumption. By connecting indoor spaces with the constantly changing light conditions outdoors, daylighting can enhance visual comfort and productivity for occupants. It can also reduce a building's total energy costs by up to one-third.

A daylighting system typically includes a combination of systems, technologies, and architectural features.

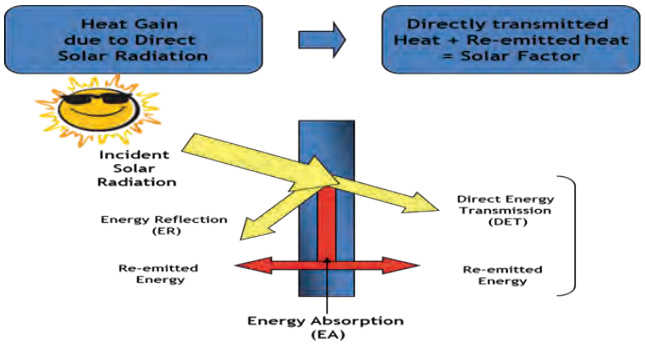

Fig. 2:

Increasing the glazing area, or the amount of glass used, is the simplest and most popular method of optimizing daylight in a space.

GLASS RELATED REQUIREMENTS LAY DOWN IN ENERGY CONSERVATION & SUSTAINABILITY BUILDING CODE(ECSBC).

The minimum permitted visible light transmittance is 27%, while the maximum permitted window-to-wall ratio is 40% (applicable to buildings demonstrating compliance using the prescriptive method, including the building envelope trade-off method). It is necessary to calculate the system U-value for the entire fenestration product, which includes the frame and sash.

Useful daylight requirements are given in below figure. (Ref. ECSBC Code 2024).

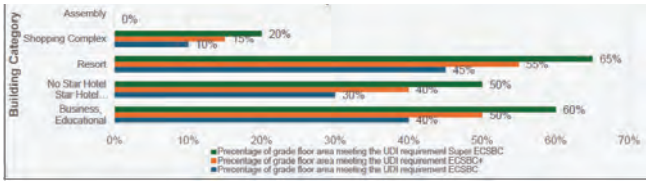

Fig. 3: UDI requirement

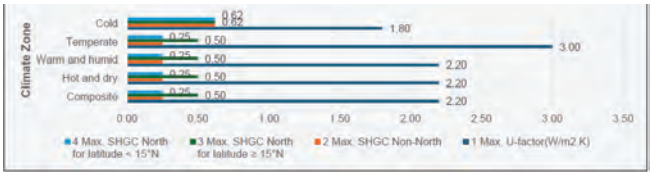

Fig. 4: U-factor and SHGC requirements for ECSBC buildings

Fig. 5: U-factor and SHGC requirements for ECSBC+ buildings

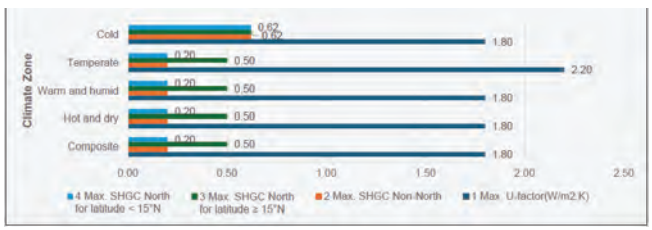

Fig. 6: U-factor and SHGC reqiurements for super ECSBC buildings

GLASS RELATED REQUIREMENTS LAY DOWN IN ECO-NIWAS SAMHITA(ENS)

Requirement for visible light transmission (VLT) in relation to window-to-wall ratio (WWR).

WWR is the ratio of the area of the non-opaque building envelope components to the area of the dwelling units' envelope (not including the roof). WWR is calculated by dividing the area of the non-opaque building envelope components of dwelling units by the envelope area of the dwelling units (excluding the roof).

$WWR=Area_{(non\text{-}opaque)}/Area_{(envelope)}$.

Fig. 7: Windows-to-wall ratio (WWR)
Source: Bureau of Indian Standards (BIS).2016, NBC of India 2016

OVERVIEW ON DIFFERENT TYPES OF GLASS PRODUCTS

Float Glass

Float glass is a sheet of glass manufactured by floating molten glass on a bed of molten tin (low melting point metal), lead is also used in past to process molten glass in bath. Float method gives glass sheet uniform thickness with excellent surface and optical quality (since there is not contact of roller to surface of net usable glass). Float glass can be transparent clear, or body tinted. Float glass is widely used for architectural, general appliances, railway and automotive applications.

Solar Control Glass

Solar control glass is a high-performance coated glass product developed by the glass industry to allow sunlight to pass through a window or façade while radiating and reflecting away a large degree of the sun's solar heat. This enables indoor space to stay bright and cooler than the case would be if a normal glass were used. Because it reflects high amount of solar heat so, solar control glass is also known as reflective glass. Solar control glass helps in reducing solar heat gain in buildings and other establishments, thus reduce cooling load also and lowers the air-conditioning costs without compromising on natural daylight. Solar control glass cut UV rays and protects us from harmful UV rays that can cause skin dieses and other health related issues.

Low Emissivity (Low e) Glass

It is estimated that approximately 15% to 55% of a home's energy loss occurs through its doors and windows, with up to 90~92% of that energy escaping through the glass itself. This is where Low-E (low emissivity) glass becomes important. Low-E glass is a type of clear glass that features an ultra-thin, virtually invisible coating designed to reflect heat more effectively than standard glass. This coating reduces the glass's emissivity, allowing it to better retain heat indoors during colder months and reflect solar heat away during warmer seasons. As a result, Low-E glass contributes to maintaining a more stable and comfortable indoor temperature year-round. Low-E glass also offers protection from ultraviolet (UV) radiation. It blocks the majority of UV rays from entering your home, helping to protect not only the health of occupants but also the longevity of furnishings. UV exposure can cause the fibres in carpets, upholstery, and other materials to fade and deteriorate over time.

Safety Glass

Safety glass is a specially engineered type of glass designed to be more resistant to breakage and significantly less likely to cause injury if it does break. It is widely used in applications such as architecture, furniture, display boards, railway coaches, construction machinery, lighting fixtures, and various parts and components of appliances, equipment, and machinery.

There are two primary types of safety glass: tempered (or toughened) glass and laminated safety glass.

Tempered Glass

Tempered glass is a single pane of glass that has been heat-treated or chemically treated to enhance its strength. This process induces internal stress patterns that cause the glass to shatter into small, granular pieces when broken, rather than large, sharp shards. As a result, it greatly reduces the risk of injury. Tempered glass is about four times stronger than standard annealed glass of the same thickness and dimensions.

Laminated Glass

Laminated glass consists of two or more layers of glass bonded together with one or more interlayers of plastic materials, typically polyvinyl butyral (PVB). These interlayers hold the glass layers together even when shattered, preventing them from breaking apart and forming sharp edges. This structure ensures both safety and structural integrity, making laminated glass ideal for applications requiring high-impact resistance and security.

Insulated Glass Unit (IGU)

An insulating glass unit (IGU) typically consists of two, and occasionally more, panes of glass separated by a spacer and sealed along the edges to form a single unit. The space between the panes—referred to as the insulating airspace—is filled with either air or an inert gas such as argon or krypton to enhance thermal insulation.

Each pane of glass has two surfaces, so a standard double-pane IGU contains a total of four surfaces.

Fire Resistant Glass (FRG)

Fire-resistant glass is a specially designed glazing product—available in the form of laminated glass, single glass units, or double glass units—that is engineered to withstand extreme heat. Its primary function is to act as a barrier that prevents fire from spreading from one side of the glass to the other.

This containment allows crucial time for evacuation or for emergency responders to arrive while the fire remains confined to a specific area. In addition to resisting flames, fire-resistant glass can also inhibit the passage of smoke—a critical feature, as smoke inhalation is one of the leading causes of fatalities during fires. By limiting both fire and smoke spread, fire-resistant glass plays a vital role in enhancing safety and can be a life-saving addition to buildings and infrastructure.

E Class: Fire Resistant Glass with only integrity characteristics.

EW Class: Fire Resistant Glass with the characteristics of Integrity and Radiation control.

EI Class: Fire Resistant Glass with the characteristics of Integrity, Radiation Control and Insulation.

Solar Glass (Solar Panel)

Solar glass falls under the category of building-integrated photovoltaics (BIPV) and is designed to replace traditional construction materials in elements such as roofs, skylights, facades, and windows—while simultaneously generating renewable energy. One of its greatest advantages is its eco-friendly and sustainable nature. By allowing ample natural light into a building, solar glass reduces the need for artificial lighting and helps lower the reliance on air conditioning, contributing to improved energy efficiency. This technology represents an invisible energy revolution. A single building equipped with solar glass can offset CO_2 emissions equivalent to 2.2 million vehicle miles—twelve times more than conventional solar panels. When integrated into architectural designs, solar glass is engineered to outperform rooftop solar systems by up to 50 times in energy output. Unlike traditional rooftop installations limited by space, solar glass leverages the vast surface area of building facades and windows, unlocking new potential for large-scale clean energy production.

EMBODIED ENERGY AND CARBON

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery.

Similarly, the embodied carbon of a building encompasses the total carbon emissions associated with all materials and processes used across its entire life cycle. According to recent data, the average Indian contributes approximately 1.32 tons of carbon emissions annually. To address this, India has set an ambitious climate agenda: aiming to decarbonize its energy sector by 50% and reach 500 GW of fossil fuel-free energy capacity by the year 2030.

As the nation targets net-zero emissions by 2070, the actions taken in the next five years will be critical in laying a strong foundation.

Embodied energy and carbon of common construction material

Although the precise embodied energy and carbon impact of construction materials varies depending on

their specific application, float glass has an embodied energy of 15 MJ/kg and an embodied carbon value of 0.85 kg CO_2/kg. These figures are significantly lower than those for materials like aluminium (155 MJ/kg and 8.24 kg CO_2/kg), stainless steel, ceramic sanitary ware, iron, and mineral fibre roofing tiles. However, float glass has a higher environmental impact than concrete, which has an embodied energy of 1.1 MJ/kg and embodied carbon of 0.16 kg CO_2/kg.

RECYCLING OF GLASS

Glass is completely recyclable and can be recycled indefinitely without losing its quality or purity. Recycling has significant positive effects on the environment by reducing CO2 emissions, energy use, and raw material consumption.

EXCEPTIONAL ENVIRONMENTAL ADVANTAGES OF GLASS RECYCLING

Endlessly Recyclable: Glass can be recycled an unlimited number of times without any loss in quality or purity.

Conservation of Natural Resources

Reduced Energy Consumption

Reduced Greenhouse Gas Emissions

Extended Furnace Life:

No Additional Waste: Glass recycling is a closed-loop process, meaning it produces no extra waste or by-products.

MOST SIGNIFICANT INNOVATIONS IN GLASS AND GLAZING TECHNOLOGY EXPECTED IN THE NEXT 5 YEARS.

Smart Glass

Smart Glass, also called switchable glass, is a specialized glass that can alter its light transmission characteristics when exposed to an electric current or other triggers. Over the next five years, advancements in this technology are anticipated to enhance its capabilities and expand its adoption, thanks to its notable advantages in energy efficiency, privacy, aesthetics, and comfort.

Currently, there are three main types of Smart Glass:

Electrochromic

Suspended Particle Device (SPD)

Polymer Dispersed Liquid Crystal (PDLC)

Ongoing innovation in Smart Glass is expected to boost performance, allow for larger sizes, and lower costs, making it more widely available. Smart Glass is suitable for use in windows, doors, skylights, and interior partitions. However, size limitations remain a significant challenge for many applications.

Improved Energy Efficiency

The push for high-performance, energy-efficient glazing solutions continues to intensify, as stricter building codes challenge existing glass and glazing technologies to simply meet minimum standards. This trend is especially noticeable in the west coast and mountain states, where modern architecture favors large glass surfaces and regional codes demand even greater thermal efficiency.

Over the next five years, advancements in glass and glazing technology are expected to further support sustainability and performance objectives, enabling buildings to use less energy without sacrificing visual appeal. Developments in vacuum insulated glass units (IGUs), triple glazing, advanced coatings, improved insulation, and IGU compositions will give architects and building envelope consultants a growing array of evolving options to consider, as they seek the optimal glazing solutions and value for their projects.

Enhanced Security

Safety and security are key concerns for architects when specifying glazing and fenestration. The glass and glazing industry are expected to introduce stronger and more effective security solutions, with high-impact and ballistic-rated glass becoming increasingly common in residential as well as commercial settings. New materials, such as advanced PVB membranes for laminated glass, are being engineered to withstand forced entry, fire, hurricanes, tornadoes, and seismic events. These innovations aim to offer improved protection against both natural disasters and human threats. As a result, new specifications for security glazing are likely to become more prominent in architecturally focused residential designs.

Lightweight Glass

With the rising demand for lightweight and flexible materials, glass and glazing technologies are advancing to address these needs. Innovative manufacturing techniques and new materials are enabling the production of ultra-thin, lightweight glass suitable for diverse uses, from eyewear and packaging to phone and computer screens, as well as glass bottles. Additionally, entirely new glass types made from titanium and zirconium—rather than traditional transparent silicon—have already been developed for certain products. These breakthroughs are expected to make their way into fenestration glazing, significantly influencing architectural design, construction, and engineering in the future.

Self-Cleaning Glass

Cleaning glass surfaces, particularly on high-rise buildings or hard-to-reach areas, is often costly, difficult, and time-consuming. While self-cleaning glass has been marketed in the past, it has not gained widespread acceptance due to questions about its effectiveness, often being seen more as a marketing tool than a practical solution. Ongoing research is focused on developing truly effective self-cleaning technologies, such as photocatalytic and hydrophilic coatings. Although it's wise to remain cautious about performance claims for now, we anticipate that new specifications for genuinely effective self-cleaning glass will eventually emerge—helping to lower maintenance costs, enhance durability, and improve the appearance of buildings.

Gel Filled Fire Rated Glass

Gel-filled fire-rated glass is a type of multi-layered glass in which sheets of float glass are bonded together with intermediate gel layers. When exposed to high temperatures, such as during a fire, these gel layers expand at around 120°C, forming a rigid, opaque barrier that temporarily blocks the spread of fire. This emerging technology in fire-resistant glass is expected to see significant advancements and wider adoption over the next five years.

Anti-Glare Glass (AG)

Anti-glare glasses are designed to minimize glare, which can lead to eye strain and headaches. Their main function is to enhance vision in environments with bright or reflective light, such as nighttime driving or working on a computer. By reducing reflections and glare, anti-glare glasses help improve visual clarity and comfort, making it easier to see and reducing eye fatigue.

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Automation of Hydroponic System by using Micro-controller

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ABSTRACT

Ever-increasing population and desertification of the evergreen area lead researchers to think of different ways of farming. Though these are enough availability of agriculture land, but the farmers are having low land holding. Hydroponics is the alternative way of farming to produce the crop despite suitable environmental conditions. The requirement of human involvement in farmland is not possible due to extreme weather conditions thus automation plays an important role. Hydroponics systems are capable of using vertical places which remain unused. The system is automated with a micro-controller, input sensors and output sensors. Our hydroponic system is capable of switching from 12-volt experimental devices to 240-volt actual farm utility devices. The micro-controller will send the information to the local server by in-build ESP32 WiFi for remote supervision and data analysis. This paper shows business model for automated hydroponic farming using device IAIHS. A sampling of desire crop was planted with input parameters to get maximum output. Switching the same device with the same input parameters in the actual hydroponic system which saves time and also minimizes the probability of losses.

***KEYWORDS** : Automated hydroponic system, I.A.I.H.S., ESP32 mmicro-controller, Sensors and actuators, Primary and secondary stages, Internet of things.*

INTRODUCTION

Cultivating a sustainable and efficient method of agricultural production has become imperative as global populations continue to expand, and cultivable land is vanishing simultaneously. In pursuit of innovative solutions, integrating technology, biology, and environmental consciousness has led to the emergence of hydroponics which was a practice that redefines traditional farming methods [1]. The purpose of this project, the Indian Automated Indigenous Hydroponic System, is to automate all the input parameters which are Nutrients, pH value, the water level in the hydroponics tank, Relative humidity, LED lights, temperature of the water and ambient temperature. All these parameters are essential for healthy plant growth. Our project Indian Automated Indigenous Hydroponic System (I.A.I.H.S.) helps to automate plant growth by giving the essential inputs as per the requirements [2].

METHODOLOGY

The methodology for this study on hydroponic growth prediction involved a systematic approach to data collection, modeling, and analysis. These parameters included relative humidity, total dissolved solids (TDS), ambient temperature, and water temperature, all of which are critical for plant health and growth. The Indian Automated Indigenous Hydroponic System (I.A.I.H.S.) was employed, integrating sensors to continuously track these conditions and an ESP32 controller to process for giving output and transmit data to the IoT platform "ThingSpeak" at regular intervals. Daily averages of the recorded parameters were compiled into a dataset, which served as the foundation for the polynomial regression analysis.

The I.A.I.H.S. (Indian Automated Indigenous Hydroponic System) device is designed to automate hydroponic farming through Internet of Things (IoT)

technology. It integrates four key sensors to monitor essential environmental conditions for plant health. An air temperature and humidity sensor (DHT22) monitors the growing environment, while a water temperature sensor (DS18b20) tracks water temperature in the tank. An electro-conductivity sensor assesses nutrient levels by measuring mineral content, and a water level indicator detects the water's presence. These sensors feed data to the ESP32 controller, which processes this information and directs the actuators accordingly.

I.A.I.H.S. consists of two stages which are primary stage and secondary stage. The primary stage is having an experimental setup, which is used before implementing it on the actual farm. This stage is essential to avoid the maximum financial losses. In the primary stage, the farmer will plant a single.

Sample of the crop and give the input parameters as per the standard value mentioned by the researcher for maximum production of a particular plant. The values of parameters should be entered carefully to ensure the precision of the I.A.I.H.S. device. The primary stage is essential as the varieties of the single crop are available in the market.

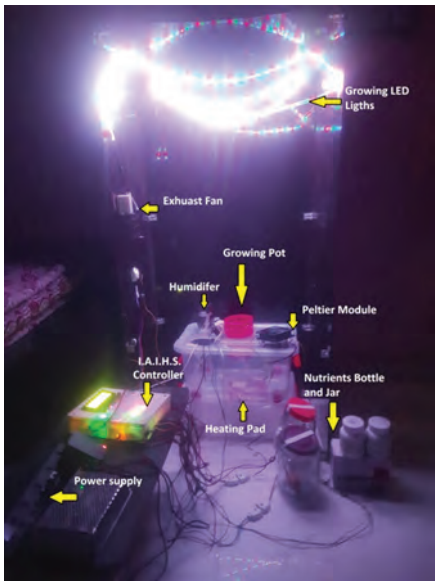

Fig. 1. a): Experimental setup for growing plants under controlled atmospheric condition hydroponically

After getting the maximum production, the same input values of the parameters in the I.A.I.H.S. device, which is used in the primary stage for experimentation, get transferred to the hydroponic farm by switching between the voltages from 12 V to 240 V. A relay driver ULN2003 was used to switch between the voltages. The ESP32 has WiFi module which helps to transfer the data from the primary stages to the local server. Therefore, farmers get a chance to take proper corrective measures in the secondary stage to avoid financial loss.

BUSINESS MODEL OF AUTOMATED HYDROPONIC SYSTEM BY USING IAIHS DEVICE

The I.A.I.H.S. uses an ESP-32 micro-controller for the analysis of the input data by the sensors and to control output parameters as per the command given. During the lifespan of the crop, ESP-32 uploads each essential input about the crop to the local server. Data can be analyzed by various software as per availability to get the standard value of every parameter required at every phase of plant life. Once the optimum input values are obtained for maximum production, the same optimum values are set for higher-scale hydroponic farming.

Primarily, farmers use the experimental setup on their I.A.I.H.S. to avoid massive losses. After getting successful results with maximum production, we can apply these same input values for the parameters (pH, EC, water temperature, relative humidity level, water level, water aerator, and ambient temperature) to the hydroponic farm through the same micro-controller. This accomplishes the second goal of the project. The experimental setup having provisions for running the actual farming equipment makes the Indian Automated Indigenous Hydroponic System different from other hydroponic systems.

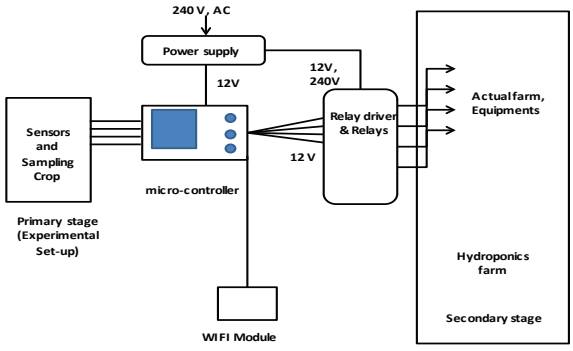

Fig 1. b) Schematic block diagram of Indian Automated Indigenous Hydroponic System (I.A.I.H.S.)

WORKING OF AUTOMATED HYDROPONIC SYSTEM

Sensors

The Indian Automated Indigenous Hydroponic System contains controlling parameters like pH, EC, water temperature, humidity level, water level sensor, water aerator, ambient temperature, and LED light. The LEDs provide red, blue, and yellow light for the photosynthesis process in the growing plant. The lights are set on for a 14-hour cycle to simulate daytime. A real-time clock (RTC) is used to keep track of the time. This system includes six sensors: the electrical conductivity probe (EC), the pH sensor (PH), the water temperature monitor sensor (DS18b20), the humidity sensor (DHT22), the anti-corrosion water level sensor, and the air temperature sensor (DS18B20). A water aerator is used to infuse oxygen into the water for the plant, which absorbs it through its roots. The electrical conductivity probe helps us estimate the amount of minerals or nutrients present in the water. The pH probes calibrated with pH buffer solutions are pH 4, pH 7, and pH 10 [3].

Nutrients in water and temperature maintenance

Measuring the pH and EC helps researchers correctly adjust the pH level and TDS value of the water before placing the young plant in the system. Due to this, the plant does not suffer from sudden shocks, which cause death. The EC and pH probes connect to a transmitter, which converts the sensor information into pH values and TDS metre readings. The distilled water had a base pH value equal to 7 and was adjusted to a range of 5.60–6.00 pH after the addition of nutrients (N, P, and K) [4]. Hydroponics nutrients solution is readily available on the market. Three submersible pumps were used in this project. The first pump is used to pump the water from the water tank to the hydroponic system after getting the input of the water level indicator present in the hydroponic system; another submersible pump is used to infuse the nutrient solution; and the last submersible is used to pump the distilled water in case the nutrients exceed the input value.

In hydroponic farming, water temperature plays a crucial role. If the water temperature fluctuates, the chance of root fatalities increases. Therefore, depending on the season, the water temperature was either heated or cooled to 24 °C or 25 °C, respectively. This thermo-electric peilter module and heating pad with micro-controller pic12f675 are used simultaneously to maintain the water temperature automatically at 24°C or 25°C, which is optimum for healthy root growth. In the summer season, when the temperature of the water is above 25 °C, the micro-controller will switch on the thermo-electric cooling module, which gives a cooling effect and maintains the required temperature. Similarly, in the winter season, when the temperature of the water drops below 24 °C, the micro-controller will activate the heating pad to heat the water to the desired temperature [5].

Ambient condition

In most plants, the ambient temperature varies with their different growing phases, and the optimum temperature is between 26 and 28 °C. Fresh air with the inclusion of carbon dioxide is provided by the inlet fan, and similarly, an exhaust fan is used to remove the warm air from the system. Humidity was provided to the plant by an ultrasonic humidifier to maintain a pleasant effect [6].

Infusing the oxygen

Oxygenation of the water is an important aspect of hydroponics. For good results, after every 90 minutes, a water aerator is to be started in the water tank for a span of 10 minutes to avoid the formation of algae and keep the water oxygenated. The time interval of the water aerator can be altered by the potentiometer [7].

Internet on things

The Indian Automated Indigenous Hydroponic System (I.A.I.H.S.) has a WiFi model incorporated with an ESP32 microcontroller [8]. All input data is transferred from the system to the local server, and it is linked with the IOT tool known as “Thingspeaks”. Thingspeak is visible from any location, provided that the service of the Wi-Fi is available in the region. Software has the provision to extract the excel file with current values of all parameter. Therefore online surveillance and data analysis of the hydroponic farming is possible. ULN2003 is the relay driver used to switch the setup from a small-scale hydroponics system to a large-scale hydroponics system by supplying the voltage that actual

agriculture instruments require to run. For primary stage all sensors and actuators work on power supply of 12 V. On secondary stage where the production is large quantity requires all the actuators to run on 240 V [9]. I.A.I.H.S. is also shows the capability to transfer the data of all parameter from large-scale hydroponics system to the local server.

MONITORING THE PARAMETERS ON IOT PLATFORM

Hydroponic systems are cutting-edge techniques for cultivating crops by growing them in a controlled, soilless environment. The automated monitoring of various environmental and system-specific parameters ensures optimal crop growth. Below is a graphical presentation of each parameter which available on IOT platform through I.A.I.H.S. device

Ambient Temperature

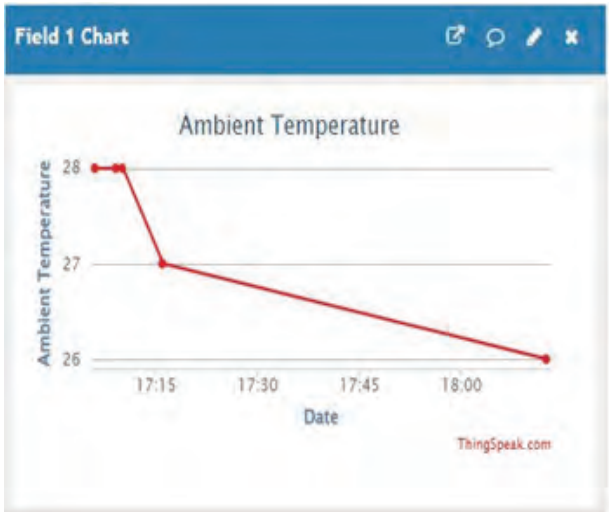

Fig. 2.a: Ambient Temperature vs. Time

The ambient temperature of the surroundings plays a critical role in plant growth (Fig. 2.a). For optimal results, the temperature must be maintained between 26°C to 28°C. If the temperature falls below or exceeds this range then Plant metabolism slows down, hindering growth and development if temperature drops below 26 0C. And above 28°C, stress conditions might arise, leading to reduced photosynthesis and potential damage to plant tissues. Modern systems utilize sensors and actuators to monitor and regulate the temperature through heaters, coolers, or ventilation systems.

Humidity Levels

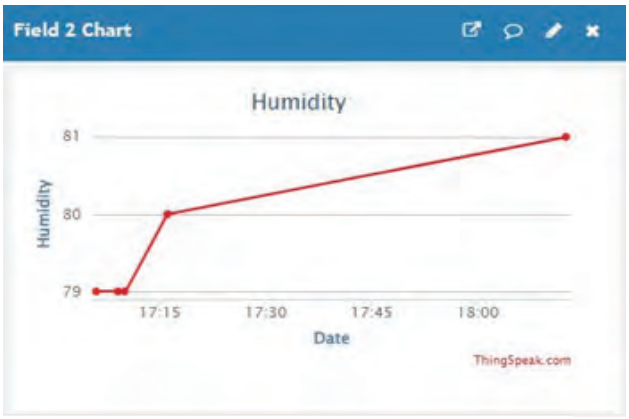

Fig. 2.b: Humidity vs. Time

Humidity in the planting area is another crucial factor. Plants rely on transpiration to transport nutrients, which is directly influenced by ambient humidity. Maintaining appropriate humidity (Fig. 2.b) prevents water loss through transpiration under low humidity and reduces fungal growth in high humidity environments. The system continuously monitors and adjusts humidity levels using dehumidifiers, misters, or ventilation, ensuring a stable environment for growth.

Water Temperature

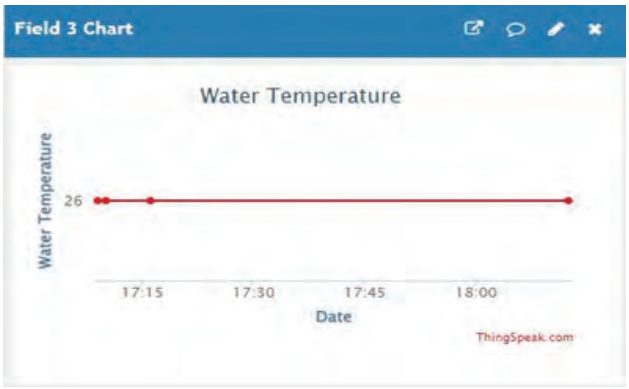

Fig. 2.c: Water temperature vs. Time

The temperature of the nutrient-rich water directly affects root function and nutrient uptake (Fig. 2.c). Optimal water temperature promotes efficient oxygen absorption by roots and prevents root rot and the proliferation of pathogens. Ideal water temperature for hydroponic systems is typically between 20°C to 25°C. Sensors monitor water temperature, and controllers adjust it using heaters or coolers as required.

pH Level of the Solution

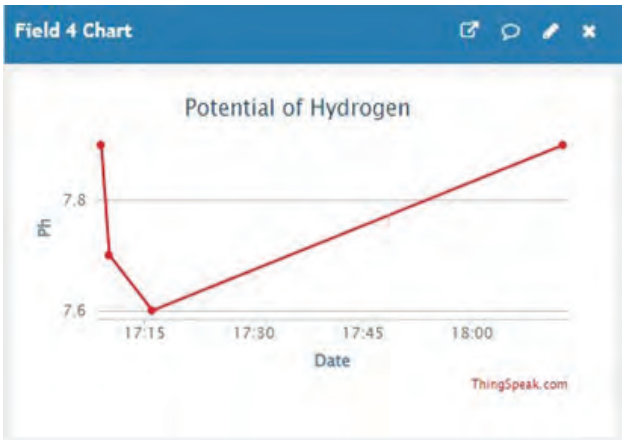

Fig. 2.d: Ph vs. Time

The pH of the nutrient solution is essential to ensure nutrient availability to plants (Fig. 2.d). Optimal Range of pH 5.5 to 6.5, slightly acidic, is preferred for most crops. Below optimal range, nutrient solubility may increase to toxic levels. And above optimal, certain nutrients may precipitate out, making them unavailable to plants.

Total Dissolved Solids (TDS)

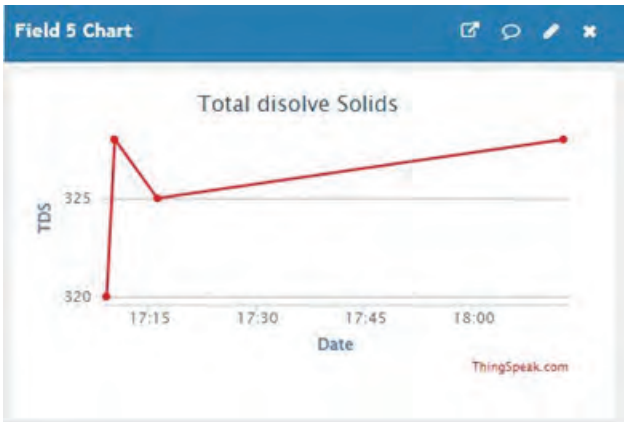

Fig. 2.e: TDS vs. Time

TDS measures the concentration of dissolved nutrients in the water (Fig. 2.e). Its ensuring the right TDS level is critical for crop health and productivity. Low TDS become insufficient nutrients can stunt growth. Whereas high TDS will give excessive nutrients which can cause nutrient burn or toxicity. The system uses EC (Electrical Conductivity) sensors to measure TDS and adjusts nutrient levels by adding or diluting the solution.

Water Level in the Tank

Fig. 2.f: Water level indicator vs. time

Maintaining the water level is essential for continuous nutrient supply (Fig. 2.f). Low Water Levels can lead to pump failure and nutrient deficiencies. Whereas high water levels may cause overflow and system inefficiencies. Water level sensors track the volume in the tank, and pumps or refill mechanisms maintain the desired levels automatically. Binary number were use maintain the water level on desire level.

Light Status

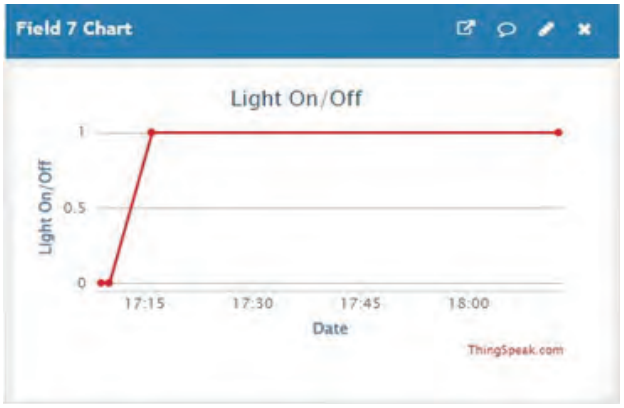

Fig. 2.g: light on/off vs. time

Light is vital for photosynthesis, the process by which plants convert light energy into chemical energy. The system monitors the status of grow LED lights (Fig. 2.g). Light "ON" indicates active photosynthesis during the photo-period. Light "OFF" ensures plants enter their dark cycle for rest and metabolic functions. Controllers automate the light schedule according to the crop's specific photo-period requirements. Graph indicates the status of light ON or OFF by binary number

RESULT

The results of this study demonstrate the effectiveness of the Indian Automated Indigenous Hydroponic System (I.A.I.H.S.) in automating and optimizing key agricultural parameters, including electrical conductivity, water temperature, air temperature, humidity, water aeration intervals and light cycles, for enhanced crop productivity. The system's two-stage process reduces financial risks by enabling parameter testing in a low-cost experimental setup before scaling up to full-scale hydroponic farming. Data gathered through IoT integration allows for precise monitoring, analysis, and control, ensuring optimal plant growth while minimizing resource wastage.

CONCLUSION

The Indian Automated Indigenous Hydroponic System was developed with a focus on controlling the growth of plants on a large scale. Abandoned buildings, abandoned warehouses, in-house vacant rooms, terraces, etc., wherever vertical agriculture is possible, an Indian Automated Indigenous Hydroponic System can be used.

A few advantages of the Indian Automated Indigenous Hydroponic System device are that there is no involvement of environmental factors and no harmful pesticides or fertilizers. The system is independent of environmental conditions and also of natural calamities. Compatible to handle the experimental setup i.e. primary stage and actual setup i.e. secondary stage setup make this system different from other system. The Indian Automated Indigenous Hydroponic System (I.A.I.H.S.) offers a sustainable and innovative solution to modern agricultural challenges by leveraging automation, IoT integration, and precise environmental control to maximize crop yield. Its dual-stage approach minimizes financial risks by enabling parameter optimization in an experimental setup before large-scale application. The system ensures efficient resource utilization and adaptability through real-time monitoring of essential parameters such as electrical conductivity, water temperature, air temperature, humidity, water aeration intervals and light. By addressing the limitations of traditional farming, I.A.I.H.S. provides a scalable and effective method for soil-less cultivation, paving the way for improved food security and sustainable agriculture, particularly in regions with limited arable land or adverse environmental conditions.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper. No financial or personal relationships influenced the research, analysis, or conclusions presented in this study.

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Navigating Challenges in Secondary Education: A Comparative Study of Assam and National Trends

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ABSTRACT

The present study provides an analytical exploration of secondary education trends and developments in Assam in comparison to nationwide trends across India during the period 2012-13 to 2023-24. Adopting a descriptive analytical methodology, the study systematically assesses secondary data derived from authoritative sources, including the Unified District Information System for Education Plus (UDISE+), reports of Ministry of Education (MoE), and relevant government publications. The analysis critically evaluates key educational indicators such as infrastructural development, student enrolment patterns, dropout rates, teacher availability, pupil-teacher ratios, and the gender parity index (GPI). Findings reveal notable advancements, particularly in female student enrolment at both national and state levels. Despite these positive trends, the research identifies continuing concerns such as persistently high dropout rates in Assam, decreasing proportions of government-employed teachers, uneven growth in government school, and inequitable access among socio-economically marginalized groups. Consequently, the study recommends focused policy measures, increased government investment in educational infrastructure, strategic recruitment and retention of qualified educators, and comprehensive inclusive educational practices to address identified disparities and facilitate equitable and sustainable educational advancement.

***KEYWORDS** : Secondary education, NEP 2020, Assam, India, Enrollment, Dropout rate, Teacher availability, Gender parity, Educational equity.*

INTRODUCTION

The secret to "social inclusion" lies in education, which is the cornerstone of sustainable growth. It is among the prerequisites for improving freedom and quality of life. Stated differently, ubiquitous access to high-quality knowledge and skills guarantees that everyone has an equal chance to participate fully in society and the workplace. Therefore, it is crucial for incorporating society's marginalized and vulnerable into the process of development. At the start of the twenty-first century, education, particularly elementary education, is a top priority on the list of nations' reform programs for both the MDGs and the SDGs, rather than domestic development policy issues. Since then, a lot of developing countries, including India, have been adhering to a somewhat condensed agenda for education development, which leaves little room for resources and policy planning for the expansion of post-compulsory education, the middle segment of the educational chain, which includes secondary and higher secondary levels.

The growing need for highly skilled workers in the global economy generates an indirect demand for secondary education. The reason for this is that secondary school graduates can be trained to meet the demands of the globalized market. Further, effective secondary schooling introduces them to formal reasoning, abstract problem-solving skills and critical thinking as well as its occupationally relevant content. Secondary education fosters the growth of aware and competent citizens who have access to both

the domestic and international economies (Lewin & Caillods, 2001). For faster economic growth, it is not sufficient to only concentrate on basic education. It is demonstrated that early development of, and public investment in secondary education produced significant rewards in East Asia (Tilak, 2001). Secondary education serves as a foundational platform for individual empowerment, economic development, and societal progress by equipping learners with critical skills, competencies, and knowledge necessary to navigate a complex globalized economy (Mukherjee, 2019). India has historically emphasized educational reforms, with specific attention to secondary education through policy initiatives such as Rashtriya Madhyamik Shiksha Abhiyan (RMSA) and Samagra Shiksha. These schemes aim at universalizing secondary education, enhancing infrastructural capacities, reducing dropout rates, and promoting inclusivity and equity in education (Mukherjee, 2019). Despite these efforts, regional disparities persist, particularly evident in Assam characterized by socio-economic and cultural diversity. Empirical evidence consistently highlights secondary education as critical for achieving gender equity, socio-economic mobility, and inclusive development, particularly among marginalized communities such as SC, ST, and OBC. Nonetheless, challenges persist, including high dropout rates, gender disparities, inadequate physical infrastructure, limited accessibility, and inequitable distribution of educational resources (Goyal & Pandey, 2021; Kingdon, 2020). Additionally, literature underscores the essential role of teacher availability and quality educational infrastructure in shaping educational outcomes. A lower pupil-teacher ratio correlates positively with enhanced student performance and educational quality, indicating the necessity of prioritizing teacher recruitment, retention, and training (Tilak, 2020). Despite considerable policy attention and resource allocation, the persistence of geographic and socio-economic disparities underscores the urgent need for context-specific interventions.

In this context, this study aims to provide a detailed comparative analysis of the trends, challenges, and progress of secondary education in Assam vis-à-vis the national scenario over the period from 2012-13 to 2023-24. The study scrutinizes critical indicators such as enrolment dynamics, dropout trends, teacher availability, infrastructural adequacy, socio-economic disparities, and gender parity. By identifying specific challenges and gaps, the research seeks to inform policymakers, educators, and stakeholders to facilitate strategic interventions aimed at fostering equitable, inclusive, and sustainable educational development.

MATERIALS AND METHODS

The study is a descriptive one. Secondary data has been used for the analysis. Following source are being used UDISE+, MoE, Government of India, and many other government reports and publications. Progress of secondary education is evaluated in terms of certain selected indicators. For reference or comparison purposes, we used the national average as well as percentage of the different parameters. Graphs and tables are used as tools to support the discussion. The study period is chosen according to the convenience of data availability.

DISCUSSION

UDISE+ 2023-24 statistics shows that there are 14,71,891 schools in India with 98,07,600 teachers in total. A total of 3,68,63,791 and 2,71,35,514 students are enrolled in secondary and higher secondary schools respectively. The secondary and higher secondary levels have gross enrollment ratios of 77.4% and 56.2% respectively. The secondary dropout rate (14.1%) is substantially greater than the primary dropout rate (1.9%). Indicators of infrastructure show that 98.3% of schools have drinking water facilities, 91.8% have electrical connections, and 95.7% of schools have restrooms for boys and 97.2% for girls. 52.3% of schools have ramps for accessibility, 89% of schools have libraries. In secondary and higher secondary education, the Gender Parity Index (GPI) is 1.02 and 1.07 respectively, indicating balanced gender representation in the classroom.

SCHOOL INDICATORS

An increasing trend is observed (figure-1) regarding the number of the total schools in India during the reference period of the present study and reaching 292850 in 2021-22. Government Schools show a consistent rise until 2017-18, after that it has slightly declined and remained stable for the rest of the period. Similarly, the Private schools also experienced steady

growth. The increase in the line showing total schools towards the end of the study period is mainly due to the increase in the number of private schools while govt. school maintained a steady presence after a significant increase in India. But in the case of Assam (Figure 2) we have seen some fluctuations particularly in the case of Government schools which shows a sharp decline in 2013-14 and after that it has stabilized in subsequent years. Whereas in the case of private schools there has been a consistent increase. The total number of secondary schools in Assam shows a steady increase during the reference period reflecting overall expansion of school network.

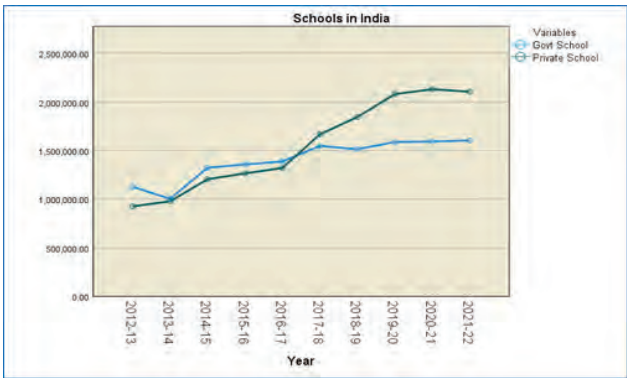

Fig. 1

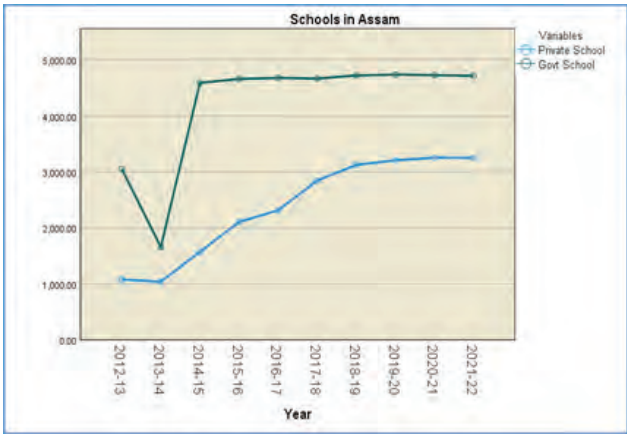

Fig. 2

ENROLLMENT AND DROP-OUT STATUS

Table-1 gives a glance of the Gross Enrollment Ratio (GER) during the study period i.e., 2012-13 to 2023-24 in India as well as in Assam which shows rise in enrollment status across gender during the study period both in secondary and higher secondary education. In India, between 2012–13 and 2023–24, the enrollment of girls in secondary education i.e., for secondary class of IX–X (78) was found to be significantly greater than that of girls in higher secondary school i.e., for higher secondary class of XI–XII (58.2). The CAGR values of girls (1.13%) also show higher than boys (0.87%), which suggests that girl's enrollment grows higher than boys' enrolment in secondary education. In class XI-XII, enrollment of girls (58.2) shows a higher rate than enrollment of boys (54.4) in 2023–24. Similarly for higher secondary education as well, girls' CAGR values (3.31%) are greater than boys' (2.43%), indicating that girls' enrollment in is growing faster than boys. If we look at the values of CAGR, the growth rate in higher secondary education is significantly greater than secondary education indicating improved transition rates. In case of higher secondary school, growth rate of enrollment is observed higher for girls (39.38 to 58.2 i.e., 18.82%) than the boys (40.78 to 54.4 i.e., 13.62%) between 2012-13 and 2023-24. This increase in growth rate pattern is also observed in secondary education.

Table 1: GER Status in India and Assam

Year	India				Assam			
	IX-X		XI-XII		IX-X		XI-XII	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
2012-13	68.17	69.21	39.38	40.78	70.07	61.01	24.59	24.66
2023-24	78	76.8	58.2	54.4	85.5	68.3	39.9	35.4
CAGR	**1.13%**	**0.87%**	**3.31%**	**2.43%**	**1.67%**	**0.95%**	**4.12%**	**3.06%**

Source: Author's Estimation and Extraction from UDISE+ Dashboard. Available at www.udiseplus.gov.in.

Similar patterns has also been observed in Assam (Table-1) where enrollment of girls (85.5) dominated the boys (68.3) in class IX-X in 2023-24. Again, in class XI-XII, the case is similar where girls (39.9) enrolment has reported slight improvement over boys (35.4) in 2023-24. For Assam as well, girls enrolment in class IX-X (85.5) has shown substantial progress over girls enrollment in class XI-XII (39.9). While comparing GER, it is observed that the girl's enrollment of secondary school (IX-X) is found to be higher in Assam than India during 2012-13 (70.07 against 68.17) to 2023-24 (85.5 against 58.2). On the contrast Boys enrollment is higher in India than Assam (69.21 against 61.01 in 2012-13 and 76.8 against 68.3 in 2023-24). India has dominated for both girls (39.38 against 24.59 in 2012-13 and 58.2 against 39.9 in 2023-24) and boys

(40.78 against 24.66 in 2012-13 and 54.4 against 35.4 in 2023-24) in terms of GER in higher secondary school (XI-XII). Like the national trends, in Assam as well, the growth rate is higher for girl's enrolment in both secondary and higher secondary education. Further the increase in growth rate is faster in respect of higher secondary education.

Table 2: Secondary Drop-Out Rate for India and Assam

Year	India		Assam	
	Girls	Boys	Girls	Boys
2013-14	14.54	14.53	27.79	25.65
2023-24	12.6	15.5	25	25.2
CAGR	-1.19%	0.54%	-0.88%	-0.15%

Source: Authors Estimation and Extraction from UDISE+ Dashboard. Available at www.udiseplus.gov.in.

Table-2 shows the dropout rate for Assam and India. For India the dropout rate of girls reached peak in 2016-17 with 22.15 after that is has declined to 12.6 in 2023-24. For the boys it also reached a peak in the same year at 22.11 and then fell to 15.5 in 2023-24. The rate of decline is higher for girls than boys between 2013-14 to 2023-24. Assam has also shown the similar trend with mild ups and downs. Assam (from 27.79 to 25) as well as at national level (14.54 to 12.6) has reported slight decline in girl's dropout rate. The CAGR indicates the trends in dropout rates over time. At national level the dropout rates for girls have declined at a CAGR of -1.19%, whereas the boys dropout rates have slightly increased at a CAGR of 0.54%. However, in Assam, the dropout rates for both girls (-0.88%) and boys (-0.15%) have declined during 2013-14 to 2023-24. It is also evidenced that Assam has reported higher dropout rates for both girls and boys compared to the national level in earlier years.

ACCESS TO EDUCATION BY SOCIAL GROUP

Table 3 offers a detail picture on access to secondary education (class IX-XII) in India and Assam by social group.

For India we have found that slight improvement over the years for SC (0.09%), ST (1.33%) and OBC (0.57%) enrolment during the reference period i.e., 2012-13 to 2021-22. Among the major social group growth rate of enrolment in secondary education is higher in ST population at national level. For the Assam, as we can see from CAGR values, for SC (-0.11%), ST (-0.37%), and OBC (-0.36%) people enrolment got decreased during the study period. Assam is a multicultural state that is home to diverse scheduled castes and tribes. Thus, there is cause for concern given the state's shrinking enrollment of SC, ST, and OBC.

Table 3: Enrollment by Social Group (in %)

Year / Indictor		2012-13	2021-22	CAGR
India	% SC	8.95	9.03	0.09%
	%ST	3.80	4.34	1.33%
	%OBC	21.16	22.39	0.57%
Assam	% SC	4.75	4.70	-0.11%
	%ST	8.88	8.56	-0.37%
	%OBC	14.12	13.62	-0.36%

Source: Author's Estimation from UDISE+ Dashboard. Available at www.udiseplus.gov.in

AVAILABILITY OF TEACHERS

Table-4 shows percentage of teachers at government have declined in secondary school (IX-XII) in India from 42% in 2012-13 to 37% in 2021-22. Whereas the percentage of private teachers has improved from 34% to 49%. For Assam, a sharp decline has been observed in the availability of govt teachers i.e., from 51% to 34% from 2012-13 to 20113-14 and thereafter it reached in peak in 2014-15 with 63%. From 2014-15 significant decline has been observed and it reached 50% in 2021-22. On the other hand, the percentage of teachers at private schools in Assam improved to 39% in 2021-22 from 15% in 2012-13. The growth rate of engagement of teachers is faster in secondary private schools for both at national level as well as for Assam.

Table 4: Teacher Indicators- India and Assam (%)

Year	Govt Teacher		Private Teacher	
	India	Assam	India	Assam
2012-12	42%	51%	34%	15%

2021-22	37%	50%	49%	39%
CAGR	2.98%	3.93%	7.08%	12.61%

Source: Author's Estimation from UDISE+ Dashboard. Available at www.udiseplus.gov.in.

PUPIL TEACHER RATIO (PTR)

The PTR for secondary and higher secondary education from 2012–13 to 2023–24 is displayed in Table 5. A decrease in the PTR means that fewer students must be taught by one teacher, which raises the caliber of instruction. Assam as well India has reported a decrease in PTR for secondary and higher secondary education, where the decline in much higher in national level than Assam.

Table 5: Pupil Teacher Ratio in India and Assam

Year	India		Assam	
	IX-X	XI-XII	IX-X	XI-XII
2012-13	29	39	13	24
2023-24	16	24	11	18

Source: Author's Extraction from UDISE+ Dashboard. Available at www.udiseplus.gov.in.

GENDER PARITY INDEX

GPI which represents the level of empowerment of girls in society. Table-6 shows comparative analysis of GPI of National level and Assam for secondary and higher secondary education. At national level, GPI for class IX-X, remained consistently at or near parity (GPI=1) for most of the years, indicating balanced enrollment of girls and boys. However, for class XI-XII, the GPI increased from 0.97 to 1.07 at all India level during the study period showing gradual progress towards the gender parity. In Assam, GPI for class IX-X is consistently above 1 except 2016-17 (data not available), suggesting higher enrollment of girls over boys throughout the period and peaking at 1.25 in 2023-24. In higher secondary school (XI-XII), Assam showed stable GPI around 1 for most of the period except in 2015-16 (0.96) and 2016-17 (data not available).

Table 6: GPI in India and Assam

Year	India		Assam	
	IX-X	XI-XII	IX-X	XI-XII
2012-12	0.99	0.97	1.15	1.25
2023-24	1.02	1.07	1	1.13

Source: Author's Extraction from UDISE+ Dashboard. Available at www.udiseplus.gov.in.

PRESENT TRENDS AND CHALLENGES IN SECONDARY EDUCATION IN INDIA AND ASSAM

Recent trends indicate commendable progress in secondary education across India and particularly within Assam. Enrollment rates have notably increased, especially among female students, reflecting successful policy interventions aimed at gender parity. In Assam, girls' enrollment has surpassed that of boys at the secondary level since 2018-19, marking a significant achievement. However, despite these advancements, dropout rates continue to pose substantial challenges, remaining notably higher in Assam compared to national averages. A concerning trend is the declining proportion of teachers in government schools, paralleled by an increase in private school teachers, particularly noticeable in Assam. This shift raises concerns regarding equitable educational access, potentially exacerbating socio-economic inequalities. Additionally, while the PTR has improved nationally, Assam's progress remains comparatively modest, indicating ongoing challenges related to educational quality. Moreover, disparities in educational access among marginalized social groups such as SC, ST, and OBC have intensified, especially in Assam, reflecting persistent systemic barriers. The primary development barrier in India's secondary education system is a lack of data and information. The country's understanding of secondary education is limited by a lack of adequate monitoring and feedback systems as well as a dearth of research in the subsector (Biswal, 2011). These disparities underline the need for targeted strategies to ensure inclusive education. Relevant information is lacking, especially at the state level, where many states lack even sector-specific policy documents. To effectively address these challenges, it is essential to enhance government investment in school infrastructure and teacher recruitment, particularly in rural and marginalized regions.

CONCLUSION

This research underscores the advancements and ongoing challenges in secondary education within Assam and

India, aligning closely with the strategic objectives of NEP 2020. Notable achievements, such as enhanced enrolment rates and significant progress in gender parity, coexist with critical challenges, including high dropout rates, inadequate infrastructure, declining government teacher representation, and persistent socio-economic inequalities. To address these complexities effectively, it is crucial to amplify government investments in educational infrastructure, especially in marginalized regions (for Assam). Targeted scholarship initiatives, active community engagement, and gender-sensitive policies are essential for reducing dropout rates and fostering inclusive education. Robust implementation of NEP 2020, emphasizing vocational training, technology integration, and multilingual education strategies, alongside strategic teacher recruitment and sustained community participation, will be pivotal in achieving sustained, equitable educational growth.

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Assessing The Impact of Predictors of Entrepreneurial Intention in STEM Students

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ABSTRACT

Research on college students' intentions to launch their own businesses has been conducted from a variety of perspectives, but the findings have not yet reached a consensus. There has been a lack of integrated investigation and comparative research into the mechanisms to comprehend factors influencing Entrepreneurial Intention. This study takes into account social, psychological, monetary, and intrinsic individual factors to gain insight into what motivates entrepreneurs. This study seeks to examine four factors that are instrumental in developing an entrepreneurial mindset using data from a survey of STEM students in Gujarat's main cities. The foundation of our study consisted of 372 responses from STEM students who were inclined towards entrepreneurship. The total dataset is assessed for independent variables like self-efficacy, locus of control, self-fulfilment and need of achievement and their relationship with the dependent variable, Entrepreneurial Intention, through a variance-based SEM (Structural Equation Modelling) technique. It was found that need for achievement to be the most significant contributing factor in the establishment of a business.

KEYWORDS *: Entrepreneurial intention, Self-efficacy, Locus of control.*

INTRODUCTION

Entrepreneurs have a significant role in fostering national economic and social growth through the creation of employment opportunities, promotion of market innovation, and enhancement of competition (Kritikos, 2014; Van Praag & Versloot, 2007). It is well acknowledged that entrepreneurship serves as a potent mechanism for fostering both local and global economic activities that yield substantial societal benefits.

The assurance of employment through tertiary education has diminished as a result of prevailing global economic challenges and the rapid advancements in technology (Collins et al., 2004). The contribution and impact of entrepreneurship in the advancement of a nation's economy and the generation of employment opportunities is of utmost importance. Therefore, there is a consensus that encouraging entrepreneurship is a useful strategy for fostering economic growth and creating new jobs.

Over the course of years, there has been a remarkable rise in the proliferation of various initiatives designed to encourage and support student entrepreneurs as they explore viable alternatives to traditional wage employment. The reason can be attributed to organizational restructuring in response to heightened global market competition. As a result, the allure of wage work in established and particularly large firms has declined, resulting in a greater preference for self-employment (Kolvereid, 1996; Franke, 2004). Ultimately, in the last few years, graduate-level unemployment has risen in many countries. According to numerous studies (Katz & Gartner, 1988; Reynolds, 1995; Krueger et al., 2000), entrepreneurial intention is the strongest predictor of actual entrepreneur-based action. Hence, the central focus in the examination of entrepreneurship revolves around the inquiry into the determinants that impact the drive to initiate a commercial venture.

The central objective of our research is to provide insights into the parameters that determine the desire of STEM students to participate in entrepreneurial endeavours. By doing so, we aspire to foster a greater inclination towards entrepreneurship and, ultimately, translate this intention into tangible actions. Since students from STEM background have a natural propensity and technological tendency toward innovative ideas that can be conceptualized (from mind to market) and introduced into the mainstream economies of developing countries like India, STEM students are at the core of this study.

Statement of the problem

In this age of rapid technological advancement, the current challenge is to create sustainable jobs at large. The burgeoning population problem is also bringing with itself the cyclical problem of unemployment. Though a STEM degree alone, will not guarantee a lucrative career, but the strong correlation and overlapping skillsets between STEM students and entrepreneurs have obliged us to ponder over the predecessors that drive STEM students towards entrepreneurial careers.

LITERATURE REVIEW

There are a variety of possible theories for the factors that influence entrepreneurial intention, as revealed by prior studies in the literature. In the year 1991, Bonnet and Furnham began by examining how personality influenced the decision-making of individuals. Several investigations have demonstrated an association between entrepreneurial aspirations and characteristics like self-confidence, willingness to take risks, self of self-fullfillment and a need to achievement. However, a person is also influenced by a wide variety of other elements, including those related to culture, society, the economy, politics, the population, and technology. Situational circumstances relating to one's experiential learning, as described by Hisrich (1990), can exert either a push or a pull on individuals. Moreover, cultural and institutional contexts impact entrepreneurship as well (Wennekers and Thurik, 1999).

The findings of previous research indicates that individuals who achieve success as entrepreneurs frequently exhibit certain traits, including a strong desire for accomplishment, the capacity to maintain locus of control, a high degree of self-worth, and the ability to innovate (Abdul-Mohsin et al., 2012). Previous research conducted by Sanchez and Sahuquillo (2018) and contemporary works of Hernandez-Perlines et al in 2020, factors including self-efficacy, task commitment, social network size, technological eagerness, opportunity-seeking behavior, and resilience have been used to assess entrepreneurial orientation.

According to Douglas (1999), entrepreneurs' motivations for venturing out on their own may be traced back to their perspectives on money, freedom, risk, and hard work. His empirical research suggests that a propensity toward developing an entrepreneurial venture is linked to an individual's appetite of self-governance and a tolerance for risk. Wang and Wong (2004) found that risk aversion did not significantly affect entrepreneurial motivation, which runs counter to the results shown by Douglas. Autio (1997) has also shed light on the significance of one's outlook while deciding to pursue an entrepreneurial path. They analyze how one's beliefs about success, independence, wealth, change, and competitive rivalry affect entrepreneurial conviction. Individuals' overarching dispositions were found to moderate the impact of entrepreneurial conviction, except for competition.

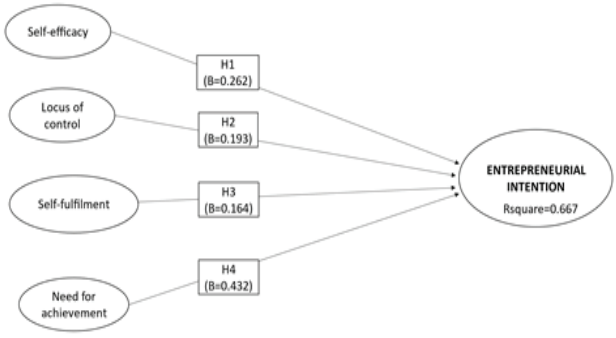

Fig. 1: Measurement Model Source: Author's research

Based on the theoretical contribution and thorough literature review, the above measurement model has been proposed. Dependent variable was Entrepreneurial Intention (EI) and independent variables were Self Efficacy, Locus of control, Self-fulfilment and Need for achievement.

The hypotheses would be as follows:

H1 : Self Efficacy has a significant impact on EI of STEM students.

H2 : Locus of control has a significant impact on EI of STEM students.

H3 : Self-fulfilment has a significant impact on EI of STEM students.

H4 : Need for achievement has a significant impact on EI of STEM students.

RESEARCH METHODOLOGY

Pilot testing and sample design

All of the model's variables were obtained from earlier research and adjusted to suit entrepreneurial intention standards. This empirical investigation aimed to guarantee that respondents understood complex sentences and to prevent content and face validity difficulties. 60 students participated in the pilot research, but their responses weren't included. All four pre-identified constructs have alpha values over 0.70, demonstrating their internal consistency (Chou and Bentler 1995).

Ahmedabad, Gandhinagar, Navsari, Bhavnagar, Mehsana, Kutch, and Anand were the locations in the state of Gujarat from where the final survey was carried out. All of the survey was finished in the first quarter of the year 2023. Structured questionnaire responses averaged 20 minutes. 372 responses inclined towards entrepreneurship were considered as respondents of the study. The resulting dataset is adequate for variance-based SEM analysis (Myers, Ahn,and Jin 2011). The data collection was done through personal interviews. Respondents' opinions were gathered at their own educational institutions and they were instructed about the research and scale methodologies.

Demographic characteristics and measures

From the demographics data of the respondents, all the students were from science and engineering colleges pursuing their engineering studies in domain of mechanical, computer, civil and electrical engineering. All the respondents were either in the first or second year of their four-year graduation program. Out of the surveyed respondents, 37% (128) were females and remaining 63% (217) were males.

For our study, four factors make up the structural model: A person's entrepreneurial intentions were considered an endogenous variable, whereas their self efficacy (3), Locus of control (5), self-fulfillment (5), and need for achievement (3) were exogenous variables. Thus five factors create the structural model. For our study, we have recorded responses on a seven-point Likert scale, with 1 stating extremely disagree, 2 : partially disagree, 3: disagree, 4: neutral, 5 : agree, 6 : partially agree, 7 : extremely agree

Measurement Model

The measurement model was analyzed with PLS 3. Using variance-based SEM is the most reliable strategy for proposing a new, untested model (Hair et al. 2017).

Table 1: Reliability and constructs of Measurement Model

Latent Construct	Item	Factor loading	AVE	Cronbach's alpha(α)	Rho_A	CR	VIF
SELF EFFICACY	SEF1	0.9403	0.3061	0.9029	0.9302	0.9387	3.2666
	SEF2	0.8878	0.3799				2.6321
	SEF3	0.9146	0.3466				2.8846
LOCUS OF CONTROL	LOC1	0.8927	0.2917	0.9384	0.9436	0.9529	3.4277
	LOC2	0.9107	0.2767				3.6130
	LOC3	0.8964	0.2958				3.3807
	LOC4	0.8946	0.2941				3.3999
	LOC5	0.8831	0.3474				2.8784

SELF FULFILLMENT	SFT1	0.9223	0.2315	0.956	0.9568	0.9660	4.3186
	SFT2	0.9250	0.2208				4.5282
	SFT3	0.9121	0.2475				4.0407
	SFT4	0.9137	0.2555				3.9141
	SFT5	0.9379	0.1882				4.3131
NEED FOR ACHIEVEMENT	NFA1	0.9325	0.2859	0.9115	0.9123	0.9443	3.4967
	NFA2	0.9282	0.2947				3.3926
	NFA3	0.9046	0.3732				2.6795
ENTEREPRENURIAL INTENTION	ENI1	0.9374	0.2664	0.9226	0.9568	0.9509	3.7532
	ENI2	0.9310	0.2809				3.5593
	ENI3	0.9232	0.3174				3.1504

Testing of the hypothesis of the structural model

Smart PLS 4 with 5000 bootstrapping samples has been used to assess the structural model and found no evidence of a significant change (Ringle, Wende, and Becker 2015). The research outcome (Table 4) unequivocally demonstrates that self efficacy (B = 0.1262, t = 5.18, p = 0.00), Locus of control (B = 0.193, t = 5.86, p = 0.00), self-fulfillment (B = 0.164, t = 4.32, p = 0.00), need for achievement (B =0.432, t = 10.034, p = 0.00) affect one's resolve to start a business. Within this context, all the four direct linkages have positive effects, clearly indicating that four hypothesis H1 to H4 supports the existing literature. None of the hypotheses is unsupported by the existing data sets.

In addition to that, this research adds to the impact magnitude as well as the individual prediction capacity of exogenous factors. According to these findings, the need for achievement has a very good predictive ability on Entrepreneurial Intention While the other three exogenous variables all have a medium degree of predictive ability on entrepreneurial intention. Therefore, it can be concluded that an urge/motive to attain anything in life in an individual has the strongest relationship to entrepreneurial intention (Cohen 1992). Conclusions drawn from the structural model suggest that the sum of the four exogenous factors explains 66.70 percent of the variation.

Table 2 : Hypotheses

Path Effect	Beta	M	t-value	p-value (2-sided)	Hypothesis	Result
Self Efficacy → entrepreneurial intention	0.262	0.193	5.180	0.000	H1	SUPPORTED
Locus of control → entrepreneurial intention	0.193	0.261	5.865	0.000	H2	SUPPORTED
Self-fulfillment → entrepreneurial intention	0.164	0.165	4.323	0.000	H3	SUPPORTED
Need for achievement → entrepreneurial intention	0.432	0.431	10.034	0.000	H4	SUPPORTED

FINDINGS AND DISCUSSION

This study has theoretical and practical consequences for academics and politicians interested in encouraging entrepreneurial spirit among STEM students. Findings suggest that need for achievement has the strongest correlation with entrepreneurial intention among STEM students, This research is useful for governments, policymakers, universities, and entrepreneurship schools because it envisages the most crucial parameters in an ecosystem that would inspire STEM students to exhibit entrepreneurial behaviour. Further, because Self efficacy has a high correlation with Entrepreneurial Intention, it is possible to stimulate the entrepreneurial passion of STEM students by providing entrepreneurial advisory and economic assistance services, consistently cultivating a corporate entrepreneurship environment

and culture at the university, and advocating for government policies that support entrepreneurial activities. Educational institutions that adhere to these principles may be successful in channelling the entrepreneurial zeal of their STEM students into actual business plans and operations. By encouraging collaboration between businesses, universities, and government agencies, and cultivating a culture of innovation, we may be able to create a better ecosystem for budding entrepreneurs.

CONCLUSION, FUTURE SCOPE AND LIMITATIONS

This research could be the foundation for further studies on the revolving around aspiring entrepreneurs. On the basis of outcomes derived through statistical techniques, it may be concluded that need for achievement is most strongly associated with a desire to establish a business, the locus of control and other factors being secondary. As a result, STEM students would be displaying better inclination in grabbing and pursuing those entrepreneurial opportunities when they foresee tangible and intangible rewards. In the current investigation, several critical determinants have been found. Future studies can build on this foundation to investigate the factors that capture the latent attributes that influence people's intentions to engage in entrepreneurial activity. The longitudinal data is more likely to examine the core processes that underlie the desire to launch a firm. The cross-sectional design of this research raises difficulties in drawing generalizations from its findings. The future trajectory of students' entrepreneurial aspirations is uncertain due to the limitations of current measurements, which mostly capture their present state.

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A Methodical Review Related to Financial Management of Banks with Special Reference to Co-Operative Banks

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ABSTRACT

The current study is a comprehensive literature review by searching for relevant academic articles, books, reports, and other scholarly sources pertaining to cooperative banks. This will provide a solid foundation for understanding the current state of research and identifying any existing gaps or limitations. These gaps might include unanswered research questions, unexplored areas, or potential contradictions or inconsistencies in the existing literature. Identifying these gaps can serve as a basis for formulating research objectives and questions for further study. After in-depth study of literature on cooperative banks and commercial banks, it was clear that there is huge scope for study in the area of financial management and financial performance of co-operative banks. These type of study are very rare, since many researchers only conducted study on profitability, financial position and growth of commercial banks only. However in the current study more concentration was given on literature review for the financial management and financial performance of co-operative banks. The study will be effective and useful for exploring areas in comparative analysis of State cooperative banks in northeast using CAMELS as a tool for measuring financial performance.

***KEYWORDS** : State cooperative banks, Urban cooperative banks (UCB), Commercial banks, Private banks, Performance analysis, Banking Finance.*

INTRODUCTION

The current study is a comprehensive literature review by searching for relevant academic articles, books, reports, and other scholarly sources pertaining to cooperative banking. This will provide a solid foundation for understanding the current state of research and identifying any existing gaps or limitations. These gaps might include unanswered research questions, unexplored areas, or potential contradictions or inconsistencies in the existing literature. Identifying these gaps can serve as a basis for formulating research objectives and questions for further study.

OBJECTIVES OF THE STUDY

1. To collectively study the literature available in the area of Indian Cooperative banking sector.
2. To find research gaps by exploring previous reserchers in this area.
3. To build a research proposal using the literature study that was not covered in the Indian cooperative banking sector.

RESEARCH METHODOLOGY

The current study is not done with any financial data; however this study purely deals with the literature review conducted on the published data. The study was quite broaden by including other commercial banks, opinion based articles of reputed news journals and other banking papers to support the study in depth. Hence, the study takes us to the area of banking, cooperative banking and performance analysis of these banks in the recent time. With the financial study few research articles related to the work life, growth, fund

management, profitability and challenges of cooperative banks are also added to make the study more effective in terms of the targeted area.

A methodological approach with four steps is applied here to complete the study.

1) Searching the articles using the key words in the available resources.
2) Criteria were set for the data to be included and excluded.
3) Basic screening process was carried out in selecting the specific paper.

LITERATURE REVIEW

Sharma, V. L., & Jindal, M. (2022)1 examined cooperative and commercial banks like any other bank. However, they were required to register under the "Co-operative Societies Act." There were a total of 1939 cooperative banks in operation in India; 76 of these were scheduled banks, and the rest were not. Twenty financial ratios for the "Uttarakhand State Co-operative Bank, the "Nainital District Co-operative Bank," the "Dehradun District Co-operative Bank," the "Kurmanchal Urban Co-operative Bank," and "the Almora Urban Co-operative Bank" have been evaluated in this study. Included in these 20 financial statistics were measures of liquidity, capital structure, activity, profitability, and more. Based on the data, can see that the Almora urban cooperative bank has an owner's capital of 11.94%, that the "Dehradun district co-operative bank", the "Kurmanchal urban cooperative bank", and the "Almora urban cooperative bank" all receive more than 80% of their financing from deposits, and that the former three each earn net profits of 8.93%, 8.71%, and 10.03%, respectively, while the latter only earns a net profit of 3.77%. This research helps gain insight into the state of Uttarakhand's cooperative banks, their organizational structure, the number of staff members typically assigned to each branch, and the amount of revenue generated by each employee.

Aarathi, K. U. et. al., (2020)2 acknowledged that today the lending industry was among the most rapidly expanding industries, and significant resources have been allocated to the banking industry. There was a high degree of complexity involved, and a thorough assessment of its effectiveness was essential. It was possible to evaluate standard bank practices using several different models. Here, utilizing the CAMEL model to predict the financial report of Bharat Cooperative bank. This approach considered Adequate Capital, Effective Management, High-Quality Assets, Sufficient Liquidity, and Profitability. The financial performance of the "Bharat Cooperative Bank" throughout the years 2014-2018 would be analyzed. The research was done using information from the relevant in-situation annual report. Researchers used 19 CAMEL-related ratios to measure the bank's performance. Overall, the analysis showed that the level of capitalization was enough. When Asset quality was taken into account, it was found to be wanting. Management's efficacy was likewise below par. The bank's overall profitability and liquidity were evaluated as satisfactory.

Rane, S. S., & Sukthankar, S. (2020)3 stated that the "asset quality of scheduled commercial banks" in India continues to decline, and researchers' focus has turned to the trend in NPA and its effect on the bank's financial performance. The study covers 15 years of data (2004-2005 to 2018-2019) on the performance of 87 commercial banks (20 public, 22 private, and 45 international). Using the Reserve Bank of India's website, were able to get all of the secondary data necessary for the study. The data can be analyzed using a regression model and a time trend analysis. The study's most important conclusions were that nonperforming loans (NPDs) at the banks studied were on the rise, and gross NPDs have a negative effect on profitability and a positive effect on operating costs.

Adhikari, H., & Joshi, K. (2018)4 found that "district cooperative banks" have a dual purpose: to serve the credit needs of the rural population at reasonable rates and to remain financially stable despite the current interest rate environment. There was a need for these banks to modify their operational strategy so that they could strike a better balance between their social mission and the demands of the market. In conclusion, it can be stated that the "District cooperative bank" that was tasked with financing agricultural growth as a part of rural development has been only partially successful.

Shaban,M. (2018)5 examined how nonperforming assets affect the bottom lines of public, private,

and international banks in India. The research used secondary data gleaned from the RBI database spanning 11 years, from 1 April 2006 to 31 March 2017. The data was analyzed using a basic linear regression model and descriptive statistics. Gross nonperforming assets (NPA) and net NPA were used as "independent variables," while "return on assets (ROA)" and "return on equity (ROE)" were the "dependent variables". All banks studied had their profits impacted negatively by nonperforming assets (NPA); however, the impact on foreign banks was the smallest compared to those in the public and private sectors.

Prasad, J. V. K., & Kaushal, M. K. (2018)6 the purpose of the study was to evaluate the efficiency and effectiveness of commercial banks in India. Specifically, the indicators in question were the Credit-Deposits Ratio, the Investment Deposits Ratio, and the "Share of Scheduled Commercial Banks in Priority Sector Lending," as well as the Aggregate Deposits activated by Scheduled Commercial Banks, credits, and speculations made by the commercial banks, and so on. The study examines the operational efficiency of all commercial banks in the country over ten years. The study indicated that Indian commercial banks have been contributing to national growth and have had generally satisfactory performance throughout the period covered by the study.

Sinha, A., & Kundu, D. (2018)7 looked at how Scheduled Commercial Banks have been financing the priority sector and its subsectors. The study uses secondary data from 2005-2015. The study focused not just on the priority sector as a whole, but on subsets within it. The results of various banks' lending activities were also analyzed. The numbers reveal staggering growth in student loans, loans to the micro, small, and medium enterprise sector, and loans to the agricultural sector, in addition to loans to the poor. Housing and microcredit, in contrast, were growing at far slower rates. Additionally, there was little to no dispersion among the loan types as measured by the coefficient of variance. Concerning the various banking sectors, it's clear that the public sector plays a significant role, but that the private sector's rate of increase in disbursement was higher than that of the public sector. When comparing the means of different types of banks, find a substantial variation.

Anbalagan, G. (2017)8 innovated like the Unified Payments Interface (UPI), widespread use of cloud computing, etc., have helped to boost the Indian banking industry in the current fiscal year. Banking difficulties include adapting to consumers' shifting wants and expectations, staying abreast of emerging rules, and developing cutting-edge banking technologies. Today, banknotes and electronic banking coexist. As well as providing liquidity and security, India's monetary system can issue a brand-new instrument. When banks in India were first established, The advent of the card, ECS in the 1990s, EFT, RTGS, NEF, mobile banking, and online banking were just a few examples of the many "technological advancements" in the banking industry. The study focused on recent developments in banking technology in India.

Biswas, B. (2017)9 examined the effect of nonperforming assets on earnings and profits, compared the 10 private commercial banks in India that were chosen based on their market capitalization and investment in assets, and covered the period of 1 April 2011 to 31 March 2016, and found no significant differences. Methods including ratio, percentage, ANOVA, Karl Pearson's simple correlation, and multiple "correlation and regression" were used to analyze the data that had been gathered from the money control website. The research found that the selected private sector banks' net nonperforming asset ratios were significantly lower than their profitability ratios. There was a statistically significant difference in profitability among the 10 private banks that were analyzed, but there were no differences in terms of nonperforming assets, return on net worth, or earnings per share. Nonperforming assets had a strong relationship and impact on the Federal Bank's net profit, return on net worth, and earnings per share, but not on those of the other 10 private banks.

Waraich, S., & Dhawan, A. (2016)10 focused on the primary function of cooperative banks, that being to offer timely and inexpensive advances to farmers. An effort was made in the study to use the CAMEL Model to evaluate the efficiency of six representative District Central Cooperative Banks (DCCBs) in Punjab. Mathematical and statistical methods, such as mean, compound annual growth rate, and t-test, have been used for data analysis. A capital adequacy ratio of 7% was required. However, the DCCBs in Sangrur, Mansa,

and Gurdaspur were found to be below that mark. The DCCBs' NPAs were all quite low, and their asset portfolios were all solid.

Tripathy, S. & Yadav, R. N. (2016)11 examined the current state of Indian banks' nonperforming assets. The primary goal of the research was to analyze the nature of "non-performing loans" (NPAs) and the recent trends in NPAs among public, private, foreign, and scheduled commercial banks in India. Research papers, publications, journals, and the RBI website were scoured for secondary data from 2003-2004 through 2012-2013. The simple average method of data analysis revealed that public sector banks in India had significantly more nonperforming assets (NPAs) than private, foreign, and scheduled commercial banks in the country.

Sulaiman, E. K. (2016)12 studied that the ratio of banks' loans to their customers' deposits would be an important indicator of banks' effectiveness in fostering economic growth. The study attempted to examine why commercial banks in rural areas have a lower credit-deposit ratio than those in urban areas, and it also assessed the financial institutions' effectiveness in lending to priority sectors. Priority sector lending guidelines established by the Reserve Bank of India have been met by commercial banks in Kerala, according to the report. But it was found that the ratio of loans to deposits at public sector banks varied significantly across rural and urban locations. There were also notable discrepancies between public and private banks in priority sector lending.

Brauers, W. K. M., et.al. (2014)13 found that there have always been financial crises, and researchers have been interested in the field of judging the financial stability of commercial banks for more than a century. In the study, it was demonstrated that the Lithuanian financial system relies on banks and that household deposits were its main source. The study also shows that the stability of the system depends mostly on how depositors act.

Sethi, A. S., & Bajaj, A. (2013)14 served a dual function, utilizing two-way ANOVA to see if there were significant differences in the "Credit-Deposit (C-D) ratio of Scheduled Commercial Banks" across 17 of India's most populous states. Looked at the convergence between states concerning C-D ratios and the degree to which C-D ratios were unstable (using two different measures). A second focus of the research was the correlation between the C-D ratio and the total and per capita incomes of the Indian states. To do this, have used a panel data estimation strategy that incorporates both fixed effects and random effects modeling [with the appropriate use of Hausman's (1978) test procedure]. According to the primary data, the C-D ratios of scheduled commercial banks varied greatly from one state to the next. In addition, the C-D ratio tended to be larger in states with higher per capita income, a larger share of income from non-primary industries, and a lower population density.

Das, S. K. (2012)15 compared district "Cooperative Banks and Primary Agricultural Cooperative Societies" that fall under the purview of State Cooperative Banks. They have been crucial to the growth of India's rural economy. The study analyses the expansion and improvement of State Cooperative Banks in India's Far Northeast. Moreover, an attempt has been made to compare and contrast the performance of State Cooperative Banks in the Northeast with those in India using several carefully chosen financial measures. Based on the Compound Annual Growth Rate, all financial variables ("capital, reserves, deposits, advances, demand, collection, and overdue") were shown to have expanded at a faster rate between 2002 and 2009.The study considers State Cooperative Banking in India's Northeast, which would be widely regarded as the country's poorest region. In addition, the report analyses the challenges and inadequacies that the State Cooperative Banks in the area confront. Finally, the analysis of several financial indicators reveals that North-eastern State Cooperative Banks lag behind their counterparts across the rest of India.

Gupta, J., & Jain, S. (2012)16 centred on the cooperative financial institutions in Delhi (India). It was for this reason that an investigation into the bank's profitability and the terms of its loans to clients was conducted. The client has taken out numerous loans from various financial institutions. To compete with the private sector, they recommended that the bank implement modern banking technologies such as automated teller machines, Internet banking, credit cards, etc.

Kumar,N. (2012)17 used several metrics, such as the number of bank branches and ATMs per area, the ratio of credit cards to cash deposits, and the distribution of

bank locations across India, to evaluate the banking industry's contribution to the country's push for greater financial inclusion. By analyzing the data, concluded that the number of scheduled commercial bank branches had decreased in rural areas between 1991 and 2001, but it had increased dramatically in semi-urban and metropolitan areas. There has been a general growth in the number of branches across all regions since 2008, albeit the increase in rural areas has been rather modest in percentage terms. Even though credit account growth was concentrated in metropolitan regions, concluded that population and regional differences persisted. When compared to the Northern, Southern, and Western regions, which saw a higher concentration of saving and credit accounts, the Northern, Eastern, and Central regions recorded low numbers. Not only that, but there has been a huge boom in the use of ATMs, but it hasn't kept pace with the population boom.

Hooda,V. (2011)18 investigatedthe ratio of cash deposits to total deposits, the ratio of investment deposits to total deposits, and the ratio of credit deposits to total deposits, all of which varied significantly among Scheduled Commercial Banks (SCBs). The research showed that the C-D ratio of SCBs was significantly related to that of State Co-operative Banks, though only indirectly (SCBs). Through the application of various ratios ("such as total advances to total assets, borrowing to deposits, total advances to deposits, and investments to deposits"), one can draw various conclusions.

Kumar,C.,&Mishra,S. (2011)19 analyzed the "number of deposit and credit accounts," the number of bank branches, the average deposit and credit per account, and the demand indicator of household-level access to "saving, credit, and insurance facilities from formal and informal sources" of financial service to measure and comprehend financial inclusion in 2002 and 2003. In terms of rural and urban performance, they discovered that Pondicherry state did well in rural but not in urban regions, while Kerala state performed well in urban areas and poorly in rural areas. The survey also concluded that although certain states have a high number of bank branches and a large number of "deposit and credit accounts," these services were only available to a tiny fraction of the population, leaving the remainder of the population to rely on informal sources. Not surprisingly, many Indian states fared poorly on both measures. These included "Bihar, Uttar Pradesh, Manipur, Rajasthan, and Madhya Pradesh."

Ahmed,J.U.D. (2010)20 assessed the elements that affect commercial banks' lending to priority sectors. The researcher employed regression analysis to reach this conclusion by factoring in the percentage of delinquent loans in the priority sector alongside other factors such as interest rate, bank performance as measured by the C-D ratio, bank branch growth, business volume, etc. Bank loan deployment to priority sectors was found to be significantly impacted by two of these factors: rising late balances and the C-D ratio.

Kulshrestha,D.K. (2009)21 highlighted the district-level deposit and loan performance of U.P.'s Urban Cooperative Banks (UCB). His research indicates that during the study period, the C-D ratio of UCB increased, most likely as a result of increased funding for the priority sector and disadvantaged groups.

Devika,J. (2002)22 analyzed the performance of banks in Kerala to see how they stack up against one another. The objective of the study was to examine the roles played by governmental, commercial, and cooperative banks in Kerala's agricultural financing sector. The C -D ratio was decreasing in Kerala, according to the study. "Non-performing assets" have a considerable impact on the profitability of Kerala's banking sector. The leading financial institutions were mostly those that provide funding for farmers. Therefore, contrary to popular belief, agricultural financing does not have an impact on output.

RESEARCH GAPS AND PROPOSAL

After reviewing these many research papers and publications, it was observed that many studies are conducted in the area of fund management, growth, profitability, non-performing assets and sources and applications of funds only. CAMELS is an important tool which has been used widely for performance measurement of banks nationally and internationally too. There is a huge scope in studying the ignored or untouched areas in cooperative sector. Thus, proposed study will be financial prudence from the point of view of customers in cooperative banks will be suitable area for the study in progress also comparative analysis of

State cooperative banks in northeast using CAMELS as a tool for measuring financial performance is another area that can be explored.

Gap 1: Most of the studies concentrate only on the growth and profitability of cooperative banks. Thus, not much literature reviews available on the proposed area of the study on cooperative banks financial prudence from the point of view of customers and that too a comparative study on state cooperative banks of northeast.

Gap 2: Since step by step RBI or statutory bodies of the cooperative banks are taking many decisions on allowing these banks to invest more in Umbrella banks, detail study can be conducted regularly by monitoring the new policies and procedures.

Gap 3: There are less information and data regarding the cooperative banks as like other commercial banks to conduct study on their overall performance.

Gap 4: There is no centralized agency or institution which collectively provides the status of these banks, since these banks regulated in the state level in different way.

Gap 5: Even though the statutory bodies allow these banks to invest in the respective avenues, management of these individual banks take unique decisions which cannot be club together and make general conclusions.

Gap 6: Only financial data available can be used to identify their investment patterns; however availability of future investment plans can be used to advise the banks on the future profitable investments.

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Content Quality in Social Media Marketing: A Key Driver of Consumer Buying Behaviour and Purchase Intention

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ABSTRACT

The rapid expansion of social media platforms has transformed the way brands connect with consumers, placing content quality at the forefront of marketing effectiveness. This study examines the role of content quality in shaping consumer buying behaviour and purchase intention, with special reference to Thanjavur District. Content quality is explored through dimensions such as relevance, originality, accuracy, visual appeal, and engagement value. Using a structured questionnaire, data were collected from 250 active social media users in the district. Statistical analyses, including correlation and regression, reveal that high-quality content significantly enhances brand trust, perceived value, and consumer engagement, which in turn positively influence buying behaviour and purchase intention. The findings highlight the need for marketers to prioritize well-crafted, authentic, and audience-focused content to maximize the impact of social media marketing campaigns. This research provides practical insights for businesses aiming to optimize their digital strategies and contributes to the growing body of literature on social media marketing effectiveness in regional contexts.

KEYWORDS *: Content quality, Social media marketing, Buying behaviour, Purchase intention, Consumer engagement.*

INTRODUCTION

Advancements in digital technologies, coupled with the swift growth of social media platforms, have reshaped the marketing landscape, offering businesses new and innovative ways to connect with and engage their customers [1]. Social media is no longer a space reserved for personal networking; it has emerged as a powerful marketplace where brands can interact directly with audiences, build relationships, and influence purchasing decisions. Within this dynamic environment, the quality of content shared has become a decisive factor in determining the effectiveness of marketing campaigns [2]. High-quality content captures attention, fosters trust, and strengthens consumer-brand relationships, ultimately influencing both buying behaviour and purchase intention [3].

Content quality in social media marketing is multi-dimensional, encompassing attributes such as relevance, originality, accuracy, clarity, creativity, and visual appeal [4]. These elements work together to ensure that marketing messages are not only seen but also valued by consumers. In a competitive digital ecosystem where countless brands vie for attention, businesses that deliver content aligned with consumer needs and preferences have a significant advantage. Poor-quality content, on the other hand, risks disengagement, loss of credibility, and diminished consumer loyalty, making content quality an essential aspect of strategic marketing planning [5].

The modern digital consumer is highly selective and discerning, a result of the information overload that characterizes the online space. With constant exposure to advertisements, influencer collaborations, and promotional campaigns, audiences are drawn toward

content that resonates emotionally and intellectually [6]. For content to stand out, it must go beyond generic advertising and focus on storytelling, authenticity, and relevance. Consumers increasingly expect brands to deliver content that adds value, whether through information, entertainment, or emotional connection, rather than simply pushing products or services [7].

In the context of regional markets such as Thanjavur District, cultural relevance plays a critical role in how consumers perceive and engage with marketing content. The integration of local values, traditions, and language nuances can greatly enhance the relatability and authenticity of a brand's social media presence. By acknowledging and respecting the cultural fabric of the community, businesses can create deeper connections with their target audience. Such localized content strategies can bridge the gap between global marketing trends and local consumer expectations, ensuring higher engagement and stronger purchase intentions.

The influence of content quality on consumer buying behaviour is rooted in its ability to shape brand perceptions, reduce uncertainty, and foster trust [8]. Well-crafted and visually appealing posts provide consumers with clarity about the brand and its offerings, making them more confident in their purchase decisions. Engaging formats such as interactive videos, polls, and live sessions encourage active participation, strengthening the bond between brand and consumer. This engagement not only impacts immediate purchasing decisions but also builds long-term loyalty [9].

Content quality is a significant predictor of purchase intention. When consumers perceive a brand's content as credible, relevant, and aesthetically pleasing, they are more likely to develop positive attitudes toward the brand, which in turn fosters a willingness to purchase. Conversely, low-quality content that lacks relevance or professionalism can lead to audience disinterest, reduced trust, and ultimately, loss of potential customers. In the age of social media algorithms that reward engagement, the quality of content becomes even more critical in ensuring visibility and reach.

SMP such as Facebook, Instagram, and YouTube serve as cost-effective avenues to compete with larger competitors [10]. In an increasingly crowded digital marketplace, these businesses must emphasise producing distinctive, high-quality content that effectively communicates their value proposition. An online presence alone is no longer enough; achieving meaningful results requires strategic content creation that reflects the brand's identity while resonating with the preferences of the target audience.

From a psychological standpoint, high-quality content has the potential to trigger both cognitive and emotional responses in consumers. Informative and factually accurate content satisfies the need for knowledge, enabling consumers to make informed choices. Simultaneously, visually appealing and creative presentations evoke positive emotions, increasing the likelihood of brand affinity and purchase intention. These psychological effects work together to move consumers from mere awareness toward consideration and eventual conversion.

Despite its importance, many businesses mistakenly prioritize content quantity over quality, believing that frequent posting guarantees better visibility and engagement [11]. This approach can dilute brand messaging, overwhelm audiences, and reduce overall effectiveness. Instead, a deliberate focus on well-researched, meaningful, and aesthetically engaging content ensures that each piece serves a purpose and contributes to the brand's overall marketing goals. Quality content may require more resources and effort, but it delivers higher returns in terms of consumer trust, loyalty, and long-term profitability. This study seeks to examine the role of content quality in social media marketing as a driver of consumer buying behaviour and purchase intention in Thanjavur District. By analyzing consumer perceptions, preferences, and engagement patterns, the research aims to provide actionable insights that marketers can use to optimize their digital strategies. The findings are expected to contribute to academic literature on social media marketing while offering practical guidelines for businesses to harness the power of high-quality content to achieve sustainable growth and competitive advantage in both local and global markets.

REVIEW OF LITERATURE

Content marketing is a strategic approach where businesses deliver relevant content at the right stage of

a consumer's buying journey to inspire purchases [12]. With society's growing reliance on the internet, it has transformed how businesses engage with customers in the digital space.

Short video content that is informative and emotionally engaging can influence the consumer buying decision process, indicating a direct positive relationship between content marketing and purchase decisions. Website content, including detailed product specifications and overall webpage design, also plays a significant role in shaping consumer purchase decisions [13]. In addition, news media content can enhance consumer trust, while celebrity-generated content online increases perceived value and strengthens online buying intentions [14]. Collectively, these elements demonstrate that content marketing has a strong positive effect on consumer buying decisions, leading to the development of the hypothesis [15].

Content marketing as a strategic approach focused on producing and delivering valuable content to attract, engage, and maintain a clearly identified target audience [16]. In a similar vein, Kotler, Kartajaya, and Setiawan define it as the practice of developing, distributing, and promoting relevant and meaningful content to foster engagement with a specific audience [17].

Social media marketing (SMM) encourages consumers to interact with a brand online through activities such as consuming, contributing, and creating content [18]. This interaction can enhance brand engagement and drive positive consumer behaviors [19]. SMM campaigns influence various consumer responses, including positive word-of-mouth, higher brand awareness, stronger brand equity, increased purchase intent, value co-creation, emotional connection, and actual purchases [20], [21], [22], [23].

In today's digital landscape, understanding consumer behaviour is crucial. This study contributes to existing research by addressing a gap in examining the combined effects of Electronic Word of Mouth, User-Generated Content, Social Media Engagement, Consumer Trust, and Impulsive Purchasing Behaviour [24].

Perceived behavioural control describes an individual's evaluation of their ability to carry out a particular behaviour. Within the scope of this study, it represents the consumer's perceived control over impulsive purchasing tendencies. Hedonic Motivation (HM) plays a significant role by introducing elements of pleasure and sensory satisfaction, which can either enhance or diminish this sense of control in impulsive buying contexts. Additionally, the Theory of Planned Behaviour (TPB) acknowledges that intentions may not always translate into actions, as external influences and limitations can affect the eventual behaviour [25].

STATEMENT OF THE PROBLEM

The rapid growth of social media platforms has transformed the way businesses interact with consumers, making content a critical tool for influencing buying behaviour and shaping purchase intentions. While brands invest heavily in social media marketing, the quality of content, in terms of relevance, credibility, creativity, engagement, and value—plays a decisive role in capturing consumer attention and fostering trust. However, despite the recognised importance of content quality, there remains a limited understanding of how its various dimensions collectively impact consumer decision-making in the digital environment. Existing research often focuses on general social media usage or promotional strategies without deeply examining the link between content quality and its psychological and behavioural effects on consumers. This gap creates a challenge for marketers in designing effective content strategies that not only attract consumers but also drive their purchase intentions. Therefore, it is essential to investigate the role of content quality in social media marketing as a key driver of consumer buying behaviour and purchase intention.

OBJECTIVES OF THE STUDY

- To examine the impact of content quality in social media marketing on consumer buying behaviour.
- To analyse the influence of content quality on consumers' purchase intentions.

RESEARCH METHODOLOGY

This study employs a quantitative research approach to examine the impact of content quality in social media marketing on consumer buying behaviour and purchase intention, using a descriptive research design to analyse relationships between variables and measure their effects. Primary data will be collected through a

structured questionnaire distributed to active social media users who engage with branded content on platforms such as Instagram, Facebook, and YouTube, with responses measured on a five-point Likert scale. A purposive sampling method will be adopted to target respondents with prior experience interacting with branded content, aiming for a sample size of 250 participants to ensure statistical validity.

The collected data will be processed and analysed using SPSS, applying techniques such as descriptive statistics, correlation analysis, and regression analysis to explore the connections between content quality, consumer buying behaviour, and purchase intention. The study will focus on social media users within a defined demographic and geographic boundary to maintain relevance and manageability of results.

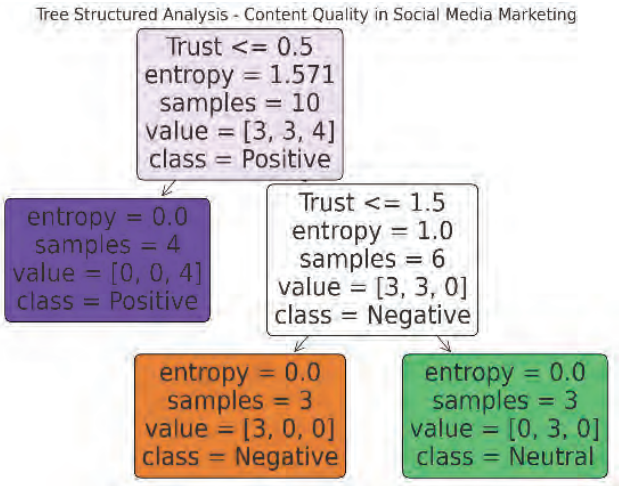
TREE STRUCTURED ANALYSIS

Tree structured analysis is a statistical and visual decision-making tool used to identify and classify the most influential factors affecting a particular outcome. It works by splitting data into different branches based on decision rules, creating a hierarchical "tree" that reveals how variables interact to shape results. Each branch represents a condition or decision point, while the endpoints (leaf nodes) show predicted outcomes along with their probability distributions. In the context of marketing research, tree structured analysis is particularly useful for understanding complex consumer behaviours, as it can capture both direct and indirect influences of multiple factors on purchase decisions. By visually mapping these relationships, researchers can easily pinpoint which variables—such as trust, content quality, or engagement—play the strongest role and how they interact. This approach not only simplifies interpretation for decision-makers but also provides actionable insights for strategy development, making it a valuable tool in both academic and business contexts.

Table 1 Tree structured analysis for Content Quality in Social Media Marketing

Node	Condition	Depth	Samples	Class Distribution	Predicted Class
0	Trust <= 0.50	0	10	[3.0, 3.0, 4.0]	Positive
1	Leaf	1	4	[0.0, 0.0, 4.0]	Positive
2	Trust <= 1.50	1	6	[3.0, 3.0, 0.0]	Negative
3	Leaf	2	3	[3.0, 0.0, 0.0]	Negative
4	Leaf	2	3	[0.0, 3.0, 0.0]	Neutral

Fig. 1 Tree structured analysis diagram for Content Quality in Social Media Marketing



The tree structured analysis for Content Quality in Social Media Marketing reveals that trust is the most influential factor shaping consumer buying behaviour. At the root of the model, trust divides respondents into groups with different likelihoods of making a purchase. Interestingly, even when trust levels are low, the presence of high-quality and engaging content can still drive consumers toward positive purchase intentions. This finding suggests that compelling content can, in some cases, compensate for trust deficiencies, making it a powerful tool for marketers. For consumers with moderate trust levels, the results are more mixed, with responses split between neutral and negative behaviours. This outcome indicates that trust alone is insufficient to guarantee a purchase. Without strong supporting factors such as content relevance, creativity, and emotional appeal, moderate trust does not translate into action. In fact, when paired with low-quality or irrelevant content, moderate trust levels tend to result in negative buying behaviour, highlighting the importance of delivering content that truly resonates with the target audience. The analysis also shows that average-quality content in the presence of moderate trust often leads to neutral behaviour, where consumers neither reject nor commit to a purchase. This "hesitation zone" underscores the need for brands to move beyond average content if they aim to actively influence consumer purchase decisions. Overall, the findings emphasise that while trust is a critical driver, it must work hand-in-hand with high-quality, relevant, and engaging content to maximise its

impact on consumer buying behaviour and purchase intention.

SUGGESTIONS

The tree structured analysis of Content Quality in Social Media Marketing highlights that while trust is the primary driver of consumer buying behaviour, its impact is significantly amplified when combined with high-quality and engaging content. Based on the findings, the following suggestions are proposed:

First, brands should prioritise trust-building initiatives such as transparent communication, consistent product quality, customer testimonials, and authentic brand storytelling. Strengthening trust will create a solid foundation for long-term consumer relationships.

Second, marketers should invest in creating high-quality, relevant, and emotionally engaging content that resonates with the target audience. This includes visually appealing designs, informative product details, and storytelling elements that connect with consumers on a personal level. Third, brands should focus on enhancing audience engagement by encouraging interactions through polls, Q&A sessions, contests, and user-generated content campaigns.

Higher engagement not only boosts brand visibility but also strengthens consumer loyalty. Finally, efforts should be made to avoid "average" or generic content, as it often leads to neutral buying behaviour. Personalised, creative, and platform-optimised content will be more effective in converting hesitant consumers into active buyers. Integrating these strategies will allow companies to leverage both trust and content quality to maximise purchase intentions and foster long-term customer commitment.

CONCLUSION

The tree structured analysis for Content Quality in social media Marketing confirms that trust, content quality, and engagement are critical determinants of consumer buying behaviour and purchase intention. Trust emerged as the most influential factor, yet its effectiveness is greatly enhanced when paired with high-quality and relevant content. The results show that even when trust levels are low, compelling and engaging content can positively influence purchase decisions, while moderate trust without strong content often leads to hesitation or negative behaviour. These findings underscore the importance of integrating trust-building strategies with content excellence to achieve maximum impact in social media marketing. Brands that deliver authentic, valuable, and engaging content while maintaining transparency and credibility are more likely to convert interest into purchase intention. In essence, success in the digital marketplace relies on the synergistic effect of trust and content quality, making them indispensable elements of a winning social media strategy.

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Emotional Influences on Consumer Decision-Making in the Herbal Product Market: A Study of Calicut and Kannur Districts, Kerala

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ABSTRACT

This study explores the emotional factors influencing consumer decision making in the herbal product market with special reference to the districts of Calicut and Kannur in Kerala. As consumer preferences shift towards natural and wellness-oriented products, emotions play a significant role in shaping perceptions, trust, and purchase intentions. The research aims to identify how emotional responses such as trust, nostalgia, satisfaction, and perceived health benefits impact the buying behavior of consumers toward herbal products. A structured questionnaire was used to collect primary data from a sample of consumers in both districts. The study applies descriptive and inferential statistical tools to examine the relationship between emotional influences and various stages of consumer decision making including product awareness, evaluation, and purchasing behavior. The findings reveal that positive emotional connections significantly influence brand preference, purchase decisions, and customer loyalty in the herbal product market. These insights offer valuable guidance for marketers to create emotionally appealing strategies that strengthen consumer engagement with herbal brands.

KEYWORDS *: Emotional influence, Consumer decision making, Herbal products, Purchase behavior, Brand preference, Consumer emotions.*

INTRODUCTION

The herbal product market in India has been expanding steadily due to increasing awareness about natural health remedies, rising concerns over the side effects of synthetic products, and a growing shift toward organic living [1]. Consumers today are more inclined to choose herbal alternatives in personal care, food, and wellness products [2]. Kerala, known for its rich tradition in Ayurveda and natural medicine, has been at the forefront of this herbal revolution. Within the state, Calicut and Kannur districts have emerged as key markets with active consumer participation in herbal product usage, creating a fertile ground for studying the psychological and emotional triggers that guide consumer behavior. Traditional consumer behavior models emphasize logical factors such as pricing, quality, and utility. However, emerging research suggests that decision- making is not purely rational; emotions play a central role in shaping consumer responses, particularly in categories involving health

and personal care. Emotions influence not only initial awareness but also product evaluation, purchase intention, and post-purchase satisfaction. In the case of herbal products, these emotional factors become even more prominent due to the product's close ties with health, culture, and tradition [3]. Herbal products often elicit strong emotional responses. Trust in the brand, fear of harmful chemicals, nostalgia for traditional remedies, and feelings of comfort associated with nature-based solutions all contribute to a consumer's evaluation and ultimate decision [4]). These emotional aspects are not just peripheral but are integral to the entire buying process. A consumer may choose a particular herbal soap or oil not solely for its ingredients but because it reminds them of familial practices or cultural identity [5]. Calicut and Kannur present a distinct cultural and consumer landscape. These districts represent a blend of modern consumer behavior and traditional lifestyle values. The people here are not only educated and health conscious but also deeply connected to regional customs and home-based remedies. This balance between the traditional and the contemporary makes these districts ideal for studying how emotions intersect with consumer choices, particularly in markets that cater to health and well-being. Although herbal products are consumed across India, there is limited scholarly focus on emotional drivers in non-metro regions [6]. Existing studies have predominantly explored consumer behavior in metropolitan cities or have focused on functional benefits of herbal products. There is a need for region-specific studies that explore the emotional dimension of herbal product consumption, particularly in districts where cultural practices and health beliefs are deeply intertwined with consumer choices [7]. Consumer emotions often stem from previous experiences, brand perceptions, and social influences. In the herbal market, where many brands emphasize their natural origin and authenticity, emotional elements like trust and familiarity become crucial. The influence of family recommendations, traditional usage, and community beliefs further strengthens emotional responses. These emotions can often override rational price- based decisions and lead consumers to choose herbal products even when cheaper alternatives are available [8].

The marketing of herbal products increasingly incorporates emotional appeal through imagery, storytelling, and cultural narratives [9]. Advertisements often highlight purity, legacy, and the wisdom of nature to form a deeper emotional bond with the consumer. In districts like Calicut and Kannur, these emotional appeals can be especially effective, as consumers often respond positively to representations that resonate with their values and lifestyles. Understanding the emotional triggers that drive these responses is essential for developing regionally relevant marketing strategies. Brand loyalty in the herbal product segment is frequently driven by emotional satisfaction rather than functional performance alone. Consumers tend to remain loyal to a brand that makes them feel safe, cared for, or connected to their roots. In markets where traditional values coexist with modern consumerism, such as in Calicut and Kannur, emotions serve as a powerful differentiator in competitive marketplaces. Emotional branding thus plays a key role in shaping long-term consumer relationships in the herbal sector.

Consumer decision-making in herbal markets involves a range of emotional influences including trust in product efficacy, perceived safety, positive associations with nature, and personal values related to sustainability and health [10]. These emotions manifest across all stages of decision-making from the recognition of a need to information search, to post- purchase evaluation. Exploring how each of these emotional dimensions aligns with consumer behavior provides a richer, more nuanced understanding of purchasing decisions [11]. The psychological underpinnings of emotional influence are supported by behavioural science, which suggests that emotions can guide, enhance, or even override cognitive processing. In the herbal product market, this means a consumer may choose a product because it feels right, not just because it scores well on logical evaluation. This emotional alignment is particularly visible in health-conscious consumers, who seek not just functional benefits but also emotional and ethical satisfaction from their purchases.

REVIEW OF LITERATURE

Emotion is a necessary ingredient to the decisions in confrontation with previous and related experiences affix values to the options that we consider. Consumers initially apply emotions amalgamated with personal feelings and experiences rather than the information of

the product such as brand attributes, features and facts many researchers state that the emotional response of a consumer has a greater influence on the decision making to buy a product. The positive emotions towards a brand in association with consumer loyalty are found more than the trust and other judgments. Marketers have developed ample theories about consumer behaviour which are found to be impractical by viewing consumer through the lence of the product [12].

The model of emotions recognition from facial expressions, have classified 22 emotions: Happy, Pride, Enthusiasm, Joy, Love, Tenderness, Ecstasy, Lust, Surprise, Conformity, Boredom, Indifference, Disgust, Fear, Revenge, Rage, Sadness, Hate, Grief, Shame, Sorrow, Anger. From these primary emotions it is possible arise others complex emotions: cheer, shame, anxiety, resignation, jealousy, hope, forgiveness, offense, nostalgia, remorse and disappointment [13].

Emotional value is found to have a significant positive relationship with green product consumer choice behavior [14]. Sheth et al. (1991) show that, when applied to purchase, product and brand decisions, emotional value has the strongest influence in discriminating between smokers and nonsmokers. The present study evaluates the moderating role of emotional value on the relationships between other consumption values and green consumer choice behavior [15].

Vijay and Suresh kumar (2019) Determinants of customer satisfaction towards herbal products in selected area of Tamil Nadu states that Ayurveda or the "Science of Life" is an ancient, holistic for diagnosis and treatment, perhaps the oldest system of medicine known to humanity. At Himalaya the research will begin with the raw herbs chosen from traditional texts both from observations and experiences of indigenous plants. The objective is to find the current herbal products scenario in India. The result of the study will help the company to identify the satisfaction level of the customers and demand of various benefits provided and promotional activities adopted by the company [16].

STATEMENT OF THE PROBLEM

The growing demand for herbal products in India reflects a significant shift in consumer preferences toward natural, organic, and wellness-oriented alternatives. In regions like Calicut and Kannur, where traditional knowledge systems and Ayurvedic practices are deeply rooted, consumers exhibit unique emotional responses toward herbal products. While functional factors such as price, quality, and availability have been widely studied, the emotional dimensions that influence consumer decision-making remain underexplored, particularly in semi-urban and culturally rich districts. Emotions such as trust, nostalgia, cultural pride, and fear of chemical products often play a subtle yet decisive role in shaping consumer behavior. However, marketers and product developers frequently overlook these emotional triggers, relying instead on generic marketing strategies that may not resonate with the target audience's values and sentiments. This disconnect can lead to ineffective branding, reduced customer engagement, and missed opportunities for building lasting consumer relationships.

Moreover, most existing research focuses on metropolitan areas and treats consumer behavior as a rational process, neglecting the emotional context within which decisions are made. There is a pressing need to understand how emotional factors influence the various stages of decision-making ranging from product awareness and evaluation to purchase intention and post-purchase satisfaction—in the context of herbal products. Addressing this gap is crucial for both academic insight and practical application in designing emotionally intelligent marketing strategies. Therefore, this study aims to investigate the emotional influences on consumer decision-making in the herbal product market, with special reference to the culturally significant and health-conscious districts of Calicut and Kannur in Kerala.

OBJECTIVES OF THE STUDY

1. To examine the emotional factors influencing consumer decision-making in the herbal product market in Calicut and Kannur districts.
2. To analyse the impact of emotions such as trust, nostalgia, and perceived safety on purchase intention and brand loyalty toward herbal products.

RESEARCH METHODOLOGY

The present study adopts a descriptive research design to examine the emotional influences on consumer decision making in the herbal product market, focusing on the

districts of Calicut and Kannur in Kerala. The objective is to explore how emotional factors such as trust, nostalgia, perceived safety, and emotional satisfaction affect various stages of consumer behavior including product awareness, purchase intention, and brand loyalty. Primary data is collected through a structured questionnaire administered to consumers who regularly use herbal products in these districts. A combination of convenience sampling and purposive sampling methods is used to select respondents from various age groups, educational backgrounds, and income levels. The sample size is determined based on the population of herbal product users to ensure sufficient representation for meaningful analysis.

The questionnaire contains close-ended questions along with a five-point Likert scale to assess the degree of emotional influence on consumer decisions. Before conducting the full survey, a pilot study is carried out to test the reliability and validity of the questionnaire. Data collected from the respondents is analyzed using statistical tools such as percentage analysis, correlation, and regression techniques to evaluate the relationship between emotional variables and decision-making behavior. In addition to primary data, relevant secondary data is obtained from academic journals, books, company reports, and government publications to strengthen the theoretical foundation of the study.

These sources help in understanding existing literature and support the interpretation of findings. The methodology is designed to ensure accuracy, objectivity, and relevance, thereby offering valuable insights into how emotional factors shape consumer choices in the herbal product segment. The findings are expected to help marketers and brand developers align their strategies with the emotional expectations of consumers in Calicut and Kannur districts.

TREE STRUCTURED ANALYSIS FOR EMOTIONAL INFLUENCES ON CONSUMER DECISION-MAKING IN THE HERBAL PRODUCT MARKET

The herbal product market in India is witnessing substantial growth due to rising awareness about natural health remedies, increased preference for organic and chemical-free products, and the resurgence of traditional wellness practices. Among the various factors influencing consumer behavior in this market, emotional influences have emerged as critical drivers of decision-making. Consumers often associate herbal products with trust, cultural values, nostalgia, and safety, which go beyond rational considerations like price or product features. These emotional triggers shape the way consumers recognize needs, evaluate alternatives, make purchase decisions, and develop brand loyalty. In a marketplace where product differentiation is often minimal and consumer expectations are evolving, understanding the emotional dimension of consumer decision-making becomes essential for herbal brands. Emotions such as trust in natural remedies, fear of harmful chemicals, attachment to traditional healing, and satisfaction from ethical consumption create a powerful psychological connection between consumers and herbal products. However, identifying and analyzing the strength and pattern of these emotional influences requires a structured and data-driven approach. Tree Structured Analysis (TSA) is a valuable method for understanding how multiple emotional factors contribute to consumer decision- making. TSA is a decision-tree-based technique that breaks down complex relationships into a hierarchical model, allowing researchers to visualize how different emotional influences branch out and affect consumer decisions at various levels. It helps in identifying the most significant emotional drivers and how they interact or combine to shape purchasing behavior. Tree Structured Analysis organizes emotional variables into a visual tree format, where each node represents a specific emotional influence, and branches represent the possible outcomes or decision paths of consumers. The tree begins with a root node (usually the most significant emotional factor) and branches out based on consumer responses, ultimately leading to decision outcomes such as product preference, purchase intention, or satisfaction. For example, the root of the tree may start with trust in the product, branching into groups that either have high or low trust. Each of these branches may then split further based on nostalgia, perceived safety, or emotional satisfaction, eventually reaching terminal nodes that represent actual consumer decisions such as brand choice, loyalty, or repeat purchase. TSA allows for the identification of:

- The most influential emotional variables.
- The sequence or hierarchy of emotional impacts.
- Combinations of emotional factors that lead to high or low decision-making outcomes.

- Segmentation of consumers based on their emotional response patterns.

This method is especially useful in understanding non-linear and interactive effects between emotional factors, which are often missed in traditional linear regression models. It provides clarity on which emotional influences should be prioritized in marketing communication and brand strategy. By applying Tree Structured Analysis to emotional influences in the herbal product market, this study aims to uncover the pathways through which emotions shape consumer decision- making. The insights derived can help marketers develop emotionally resonant messaging, culturally aligned branding, and more personalized promotional strategies that connect with the values and sentiments of herbal product consumers. The Tree Structured Analysis model developed using the CHAID method provides valuable insights into the emotional influences that affect consumer decision making in the herbal product market. In this model, the dependent variable is overall consumer decision making, while the independent variables include a wide range of emotional and promotional factors such as trust in the product, nostalgia, perceived safety, emotional satisfaction, brand attachment, cultural identity, fear of side effects, offers and discounts, social influence, and aesthetic appeal. Among the eleven independent variables entered into the model, only two were found to significantly influence consumer decision making. These were emotional satisfaction and cultural identity.

Table 1 Model summary of emotional influences on consumer decision-making in the herbal product market

Specifications	Growing Method	CHAID
	Dependent Variable	Overall Consumer Decision making
	Independent Variables	Trust in the Product, Nostalgia, Perceived Safety, Emotional Satisfaction, Brand Attachment, Cultural Identity, Fear of Side Effects, Offers and discounts, Social Influence, Aesthetic Appeal, Aesthetic Appeal
	Validation	None
	Maximum Tree Depth	3
	Minimum Cases in Parent Node	100
	Minimum Cases in Child Node	50
Results	Independent Variables Included	Emotional Satisfactions, Cultural Identity
	Number of Nodes	5
	Number of Terminal Nodes	3
	Depth	2

Source: Output generated from SPSS 21

This indicates that while consumers may consider multiple emotional and promotional factors when making decisions, emotional satisfaction and cultural identity are the most powerful in predicting their final choices. Emotional satisfaction likely serves as the most important factor, highlighting that when consumers feel emotionally fulfilled after using herbal products, they are more likely to continue purchasing and remain loyal to the brand. Cultural identity also plays a significant role in shaping consumer behavior. In regions such as Calicut and Kannur, where traditional health practices and natural remedies are part of daily life, the use of herbal products often aligns with cultural values and beliefs. This connection reinforces consumer trust and contributes to stronger emotional engagement with the product. As a result, brands that position themselves in line with cultural traditions are more likely to build lasting relationships with their customers. The decision tree generated through the analysis consists of five nodes, of which three are terminal nodes. This structure means the model divides consumers into three distinct groups based on their levels of emotional satisfaction and cultural identity. The tree reaches a depth of two, showing that the relationships between these emotional factors and consumer decision making are clear and do not require multiple layers of analysis to understand. It is important to note that other variables such as trust in the product, nostalgia, perceived safety, and offers and discounts were not included in the final model. This does not mean they are unimportant, but rather that they did not contribute significantly to differentiating consumer

behavior in this particular sample. Their influence may still be present but may operate indirectly through the stronger variables of emotional satisfaction and cultural identity. The absence of validation in the model suggests that cross-validation or testing with a separate sample was not applied. Although this is acceptable for exploratory analysis, future research may benefit from adding a validation step to ensure the model's stability and reliability. The decision tree was developed using settings that allowed a maximum depth of three, with at least one hundred cases in each parent node and fifty in each child node. These parameters were set to maintain a balance between model accuracy and interpretability. The findings of the analysis emphasize the importance of focusing on emotional satisfaction and cultural alignment when designing marketing strategies for herbal products. Emotional experiences that create a sense of trust, comfort, and well-being are more likely to result in positive consumer behavior. At the same time, aligning the brand with the cultural values and traditions of the target audience can strengthen consumer attachment and long-term loyalty. Marketers operating in the herbal product space should consider integrating emotional storytelling, cultural relevance, and personalized communication in their promotional activities. This approach will help create a stronger emotional connection with consumers, leading to better satisfaction and improved decision making in favor of their products. The insights from the Tree Structured Analysis can be used as a foundation for developing more effective and emotionally engaging marketing strategies. In summary, the CHAID model provides a clear and interpretable view of how emotional satisfaction and cultural identity drive consumer decision making in the herbal product market. These findings are especially relevant in culturally rich regions like Calicut and Kannur, where consumer choices are closely tied to traditional values and emotional preferences. The model serves as a practical tool for guiding both academic research and marketing practice in the growing field of herbal consumer goods.

Table 2 Risk of the model for emotional influences on consumer decision-making in the herbal product market

Estimate	Std. Error
1.896	.079
Growing Method: CHAID	
Dependent Variable: Overall Consumer Decision making	

Source: Output generated from SPSS 21

The risk estimate is a key statistical measure that helps evaluate the accuracy of a classification model such as CHAID (Chi- squared Automatic Interaction Detection). In this model, the dependent variable is Overall Consumer Decision Making, and the independent variables are various emotional factors such as trust, nostalgia, emotional satisfaction, cultural identity, and others. The risk estimate value is 1.896, and the standard error is 0.079. The risk estimate indicates how often the model incorrectly classifies or predicts the outcome variable. In this context, it reflects how accurately the model predicts consumer decision-making based on emotional influences. A risk estimate of 1.896 suggests that the model has some level of misclassification. It implies that there are instances where the model fails to predict the actual consumer decision-making outcome correctly. In classification trees like CHAID, lower risk values indicate higher accuracy. Since the value here is above 1, it signals that the model may not be highly precise and could benefit from further refinement. The standard error of 0.079 represents the amount of variability or uncertainty in the risk estimate. A lower standard error means the estimate is relatively stable, and we can be confident in the reliability of the result. In this case, the standard error is small, suggesting that the risk estimate is consistent and not likely to vary widely with a different sample from the same population. The overall interpretation is that while the CHAID model has successfully identified meaningful emotional variables (such as emotional satisfaction and cultural identity) influencing consumer decision-making, its predictive ability is moderate. The risk estimate indicates that although the model captures general patterns, there are still unexplained factors or variability in consumer behavior that the model could not fully account for. This result highlights the complexity of emotional influences on decision-making, especially in the herbal product market where decisions are not solely based on logic but on deep personal, emotional, and cultural values. To improve model accuracy, future research could consider adding more detailed variables, refining measurement scales,

or applying cross- validation to enhance reliability. The gain summary derived from the CHAID model offers insights into how consumers are segmented based on their emotional influences and corresponding decision-making behavior. The model has produced three final nodes, each representing a distinct group of consumers who share similar emotional characteristics and exhibit different levels of decision-making related to herbal product purchases. These segments are evaluated based on their size, their proportion within the total sample, and the mean score for overall consumer decision-making.

Table 3 Gain summary for nodes for emotional influences on consumer decision-making in the herbal product market

Node	N	Percent	Mean
4	55	11.0%	3.64
3	317	63.4%	3.16
2	128	25.6%	2.61
Growing Method: CHAID Dependent Variable: Overall consumer decision-making			

Source: Output generated from SPSS 21

Node 4 represents a smaller group of consumers, consisting of 55 individuals, which accounts for 11 percent of the total sample. Despite being the smallest segment, this group shows the highest average score for consumer decision-making, with a mean of 3.64. This suggests that consumers in this group are highly influenced by positive emotional factors and demonstrate a strong inclination to purchase herbal products. They likely feel a deep sense of emotional satisfaction, trust, and cultural connection with herbal products, which motivates their purchasing behavior. This group can be considered as highly engaged and emotionally loyal, making them a valuable target segment for marketers aiming to reinforce brand loyalty. Node 3 is the largest group in the sample, comprising 317 consumers and accounting for

63.4 percent of the total. The mean score for consumer decision-making in this group is 3.16, indicating a moderate level of emotional influence. Consumers in this segment are generally favorable toward herbal products but may not have a strong or consistent emotional attachment. Their decision-making may be influenced by factors such as mild satisfaction, moderate trust, or limited cultural alignment. While they show potential for continued engagement, this group would benefit from promotional strategies that further strengthen their emotional connection to the brand or product. Node 2 includes 128 consumers, which makes up 25.6 percent of the sample. This group has the lowest mean score of 2.61 for consumer decision-making, indicating low engagement and minimal emotional influence. Consumers in this segment may lack trust in the product, have limited satisfaction with previous use, or may not identify culturally with herbal solutions. Their purchasing decisions are less favorable, and they may require more persuasive, educational, or emotionally appealing messaging to change perceptions and encourage positive decision-making. Overall, the gain summary clearly illustrates that emotional factors segment consumers into three meaningful groups: highly engaged, moderately influenced, and low-engagement consumers. The group with the highest emotional engagement shows the strongest decision- making behavior, underscoring the importance of emotional satisfaction and cultural identity in influencing consumer choices in the herbal product market. These findings suggest that marketing efforts should be tailored to enhance emotional value, especially for those with moderate and low emotional connection, in order to move them toward more favorable and consistent purchasing decisions.

FINDINGS AND SUGGESTIONS

The study reveals that emotional factors play a significant role in shaping consumer decision- making behavior in the herbal product market. Among the various emotional influences examined, emotional satisfaction and cultural identity emerged as the most critical predictors of consumer decisions. Consumers who experienced a higher level of emotional satisfaction after using herbal products demonstrated a stronger inclination toward continued usage, brand loyalty, and positive word-of-mouth recommendations. The Tree Structured Analysis using the CHAID method effectively classified consumers into three distinct groups based on their emotional engagement levels. Consumers in Node 4 (11 percent of the sample) showed the highest level of decision-making behavior, with a mean score of 3.64. This group was found to be

emotionally satisfied and closely aligned with cultural beliefs associated with herbal usage. Node 3, which included the majority of the sample (63.4 percent), had a moderate mean score of 3.16, indicating average emotional engagement. Meanwhile, Node 2 represented 25.6 percent of the consumers who scored lowest (mean 2.61), showing minimal emotional connection or satisfaction. The risk estimate of the CHAID model was 1.896 with a standard error of 0.079, indicating moderate predictive accuracy. The gain summary also reinforced that emotional satisfaction is a stronger predictor of consumer behavior than other emotional variables such as trust, nostalgia, and perceived safety, which did not appear in the final tree model. These findings underscore the need for companies to focus more on emotional engagement rather than relying solely on functional or promotional strategies. Based on the findings, it is recommended that herbal product companies and marketers prioritize emotional satisfaction in their branding and communication strategies. Marketing campaigns should be designed to create emotional appeal by highlighting user experiences, wellness outcomes, and the natural benefits of the products. Storytelling that reinforces emotional benefits and showcases authentic testimonials can build trust and deeper emotional bonds with the target audience. Companies should also leverage cultural identity as a strategic advantage, especially in regions like Calicut and Kannur where traditional values and Ayurvedic practices are deeply rooted. Positioning products as part of one's cultural lifestyle, rooted in heritage and purity, can significantly improve consumer connection and decision-making outcomes. Packaging, brand names, and advertising language can be aligned with local traditions to create familiarity and pride. For consumers who fall into the moderate engagement group, brands should introduce loyalty programs, interactive content, and experience-based marketing to increase emotional involvement. These consumers are already positively inclined but need stronger emotional reinforcement to become fully committed customers. The segment with low emotional engagement should be targeted through educational campaigns, product demonstrations, and empathy-driven messaging that addresses doubts, builds trust, and gradually fosters emotional connections. Addressing barriers such as lack of information or cultural disconnect will be important for converting this group. Overall, the study suggests that emotional marketing should be integrated into the core of product development, promotional strategies, and customer relationship management. Brands that succeed in establishing a strong emotional presence in the minds of consumers are more likely to enjoy long-term loyalty and advocacy in the herbal product market.

CONCLUSION

The present study highlights the significant role that emotional factors play in influencing consumer decision-making in the herbal product market, particularly in the culturally rich districts of Calicut and Kannur in Kerala. As consumers increasingly seek natural and wellness-oriented products, their decisions are shaped not only by functional aspects but also by deep emotional connections. Emotional satisfaction and cultural identity emerged as the most influential predictors in shaping consumer behavior, indicating that feelings of trust, belonging, and personal value associated with herbal products are central to consumer preferences. The findings from the Tree Structured Analysis revealed clear segmentation among consumers based on their level of emotional engagement. Consumers who reported high emotional satisfaction and strong cultural alignment demonstrated more favorable decision-making behaviours such as repeated purchases and brand loyalty. In contrast, those with low emotional involvement showed weaker decision patterns and were less likely to engage with herbal brands. These insights emphasize the need for marketers and product developers to focus on creating emotionally resonant experiences through storytelling, culturally relevant branding, and consumer-centric messaging. Emotional connections not only enhance consumer satisfaction but also play a key role in building long-term loyalty in a competitive market. By integrating emotional and cultural elements into their strategies, companies in the herbal sector can strengthen their position and foster more meaningful relationships with their consumers. In conclusion, understanding and leveraging emotional influences is not just an added advantage but a necessity in the herbal product industry. This study contributes to the growing body of knowledge on consumer behavior by showing how emotional dimensions, when properly

understood and addressed, can lead to more effective marketing outcomes and greater consumer satisfaction in the herbal product market.

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Analysis of Employability Skills with Emphasis on Psychological Skills: Assessing the Impact of Skill Gap on Employee Performance in the Health Care Sector of Tamil Nadu

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ABSTRACT

The health care sector in Tamil Nadu faces increasing demands for highly skilled professionals, yet gaps persist between the skills required by employers and those possessed by employees. This study investigates the effect of skill gaps on employee performance, with a particular focus on psychological skills as a key component of employability. Using a structured questionnaire administered to employees in select health care institutions, data were analyzed through factor analysis to identify the underlying dimensions of employability skills relevant to the sector. The findings reveal that psychological skills—encompassing emotional resilience, adaptability, empathy, and stress management—emerged as a critical factor influencing both job efficiency and service quality. Other significant factors included communication skills, problem-solving ability, and technical competencies. The results underscore the need for targeted training programs aimed at bridging the skill gap, especially in psychological competencies, to enhance employee performance and patient care outcomes. The study offers practical implications for policymakers, HR managers, and educational institutions in designing skill development strategies tailored to the health care industry.

KEYWORDS *: Skill gap, Employee performance, Employability skills, Psychological skills, Factor analysis, Health care sector.*

INTRODUCTION

The health care sector in Tamil Nadu is a vital pillar of public welfare, economic growth, and technological advancement [1]. In recent years, it has experienced rapid expansion due to increasing patient demand, specialized medical services, and significant investments in infrastructure [2]. This growth, however, has highlighted a critical challenge, aligning the skills of health care employees with the evolving demands of the industry. A persistent skill gap between the competencies required by employers and those possessed by employees has raised concerns about service quality, operational efficiency, and patient satisfaction [3]. In the healthcare industry, skill gaps arise from various factors, such as outdated academic curricula, inadequate training opportunities, weak collaboration between industry and academia, and the rapid evolution of technology and procedures. While technical expertise is crucial for health care professionals, employability skills, particularly psychological skills, play an equally important role in ensuring effective patient care, decision-making, and teamwork in high-pressure environments.

Psychological skills refer to mental and emotional competencies such as emotional resilience, adaptability, empathy, stress management, and interpersonal sensitivity [4]. These skills enable employees to handle the challenges of a demanding health care environment, build trust with patients, and foster collaboration among colleagues. Inadequate development of these skills can

lead to increased stress, burnout, lower productivity, and ultimately a decline in patient care standards [5].

Employability skills encompass a wide range of competencies beyond psychological readiness, including communication, problem-solving, teamwork, leadership, and adaptability [6]. In the health care sector, these must be integrated with technical expertise to produce professionals who can deliver quality services under varying conditions. Unfortunately, skill development initiatives often focus heavily on technical training while neglecting the equally vital psychological and interpersonal dimensions [7].

In Tamil Nadu's health care industry, employers frequently report difficulty in finding candidates who possess the right balance of technical and soft skills. This imbalance impacts employee performance, patient outcomes, and the sector's overall service quality. Understanding and addressing these skill gaps, especially those related to psychological competencies, are essential for sustainable workforce development.

Tree Structured Analysis is a valuable statistical method for identifying the core dimensions of employability skills in the healthcare sector [8]. By clustering related skill variables into broader categories, it enables researchers and industry stakeholders to recognize the most crucial areas for enhancement. This method is especially effective in uncovering often-overlooked competencies, such as psychological skills, that play a vital role in influencing performance.

Although studies on skill gaps exist in other industries, there is limited research on how psychological skills influence performance in the health care sector of Tamil Nadu. Addressing this gap can provide practical insights for designing targeted training programs and improving human resource strategies in the sector. The present study aims to assess the effect of skill gaps on employee performance in Tamil Nadu's health care sector, with a special focus on psychological skills as a dimension of employability. Using factor analysis, it identifies the most critical skill clusters that impact employee performance and explores their relative importance in achieving service excellence. The findings are expected to enrich academic understanding by emphasizing the role of psychological competencies in the health care industry and offer practical recommendations for policymakers, HR managers, and training institutions. By bridging the skill gap—particularly in psychological skills—the sector can enhance employee performance, strengthen patient trust, and contribute to the long-term improvement of health care services in Tamil Nadu.

REVIEW OF LITERATURE

Recent developments indicate a stronger link between employability skills and broader employment challenges, emphasizing the shared responsibility of organizations, employers, and employees in addressing issues such as lifelong learning and sustained employability [10]. Changes in workplace practices and the transformation of organizational culture have increasingly positioned employability skills as a collective asset rather than an individual attribute [11].

In the service sector, where customer satisfaction is highly dependent on employee capabilities, selecting the most suitable candidate for each role becomes crucial. Regular training is necessary to enhance skills and prepare employees for diverse and unexpected situations. Conducting a Training Needs Analysis (TNA) is essential to identify individual strengths and skill gaps prior to designing any training initiative [12], ensuring the program's relevance and effectiveness. The present study aims to profile employees based on their employability skill sets, assessing competencies across all levels of the organizational hierarchy, particularly in line services. Within the healthcare sector's multiple verticals, this research focuses on the medical services segment, encompassing line services, support services, and auxiliary services.

Research exploring employers' specific employability skill requirements in healthcare remains limited. Messum et al. (2011) [13] identified interpersonal skills, work experience, tertiary qualifications, healthcare system knowledge, teamwork, conceptual and analytical skills, computer proficiency, financial skills, and leadership as the most frequently sought attributes in job advertisements for Health Service Managers (HSM). Senior health managers placed additional emphasis on integrity, ethical conduct, adaptability, effective communication, self-awareness, collaboration, and planning—often valuing these over technical or discipline-specific expertise. Notably, only interpersonal skills and teamwork appeared in both

the top ten advertised skills and the top ten prioritized by senior managers [14]. Furthermore, skill gaps reported in recent graduates included deficiencies in teamwork, written communication, collaboration, negotiation, computing (especially Excel), strategic thinking, environmental scanning, and self- awareness. Employers also favored graduates who demonstrated self-management, minimal need for supervision, initiative, and a strong work ethic.

Importantly, employability skills stem not only from formal qualifications but also from continuous learning in non-formal and informal contexts [15]. Soft skills are critical to success in education, work, and personal life, and are often acquired through early family interactions, observation of others, and later through formal education and workplace experiences. While some research [16] suggests that soft skills are primarily developed within educational settings, other studies highlight the influence of peer learning. For instance, Rajabzadeh [17] found that undergraduates demonstrated greater confidence in teamwork when collaborating with senior students during seminars. The presence of more experienced peers often led to stronger leadership within groups and improved performance among junior members.

STATEMENT OF THE PROBLEM

The health care sector in Tamil Nadu is undergoing rapid transformation due to technological advancements, increasing patient expectations, and growing demand for specialized services. While this progress has created new opportunities, it has also exposed a significant mismatch between the skills employers expect and those employees actually possess. This skill gap is particularly concerning in the area of employability skills where psychological competencies such as emotional resilience, adaptability, empathy, and stress management are often overlooked in favor of purely technical expertise. The absence or inadequacy of these psychological skills can undermine employee performance, compromise patient care quality, and increase workplace stress, ultimately affecting organizational efficiency. Despite the evident importance of such skills, there is limited empirical research focusing on their role in the health care sector of Tamil Nadu. Furthermore, existing training programs rarely integrate targeted psychological skill development, leaving a critical gap in workforce readiness. Given the multidimensional nature of employability skills, it becomes essential to identify and analyze the underlying factors that most significantly impact performance. A systematic factor analysis can provide deeper insights into these dimensions, enabling stakeholders to prioritize interventions that address the most pressing skill deficiencies. Without such research, efforts to improve employee performance and patient care outcomes may remain fragmented and ineffective. This study therefore seeks to address this gap by examining the relationship between skill gaps, especially in psychological skills, and employee performance in the health care sector of Tamil Nadu, identifying the core factors that require attention for sustainable workforce development.

OBJECTIVES OF THE STUDY

1. To explore and assess the primary dimensions of employability skills, giving special attention to psychological competencies within Tamil Nadu's healthcare sector.
2. To evaluate how skill gaps influence employee performance by applying Tree Structured Analysis.

RESEARCH METHODOLOGY

This study employs a descriptive research design to investigate the impact of skill gaps on employee performance in Tamil Nadu's healthcare sector, with particular emphasis on psychological skills as a key dimension of employability. This approach is selected to offer a comprehensive understanding of current skill levels, the magnitude of existing gaps, and their effect on performance outcomes.

Population and Sample

The study's target population includes employees from hospitals, diagnostic centers, and other healthcare institutions in Tamil Nadu. Respondents are selected using a purposive sampling method, focusing on individuals with a minimum of one year of work experience in the sector. The sample size is determined to meet the statistical requirements for factor analysis, ensuring adequate representation from diverse job roles, including doctors, nurses, technicians, and administrative personnel.

Data Collection

Primary data was collected through a structured questionnaire designed to evaluate employability skills, psychological competencies, and employee performance, with responses recorded on a five-point Likert scale. Secondary data was sourced from industry reports, scholarly publications, and organizational records to supplement and enrich the analysis.

Data Analysis Tools

The data is analyzed using SPSS, with descriptive statistics summarizing demographics and key trends. Factor analysis identifies the underlying dimensions of employability skills, focusing on psychological aspects. Reliability is tested using Cronbach's alpha to ensure measurement consistency.

Scope and Coverage

This study is limited to the healthcare sector in Tamil Nadu, examining only the skill gaps that affect employee performance. It places particular emphasis on psychological skills, along with other employability dimensions revealed through factor analysis.

TREE STRUCTURED ANALYSIS

The table below presents the model summary, gain node summary, and risk estimates derived from the tree analysis. Figure 1 displays the tree diagram representing employability skills in the healthcare sector in relation to psychological skills.

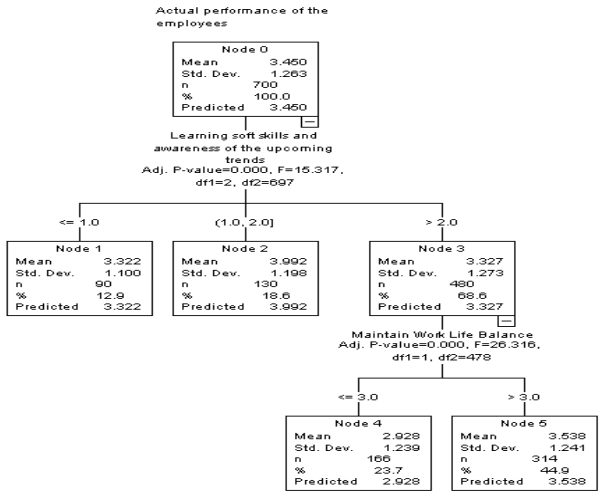

Fig. 1 Tree Diagram for the employability skills in health care sector with respect to psychology skill

Table 1 Risk of the model

Estimate	Std. Error
1.468	.069
Growing Method: CHAID Dependent Variable: Actual performance of the employees	

Source: Output generated from SPSS 21

Table 2 Model summary

Specifications	Growing Method	CHAID
	DV	Performance of the employees
	IV	Ability to Tackle Assemblages, Maintain Work Life Balance, Professionalism to work in a diverse, Flexible in adapting to new changes, discovering new opportunities, Learning soft skills and awareness of the upcoming trends, Conflict management, Accountability towards superior, Loyalty and integrity
	Validation	None
	MTD	3
	MCPN	100
	MCCN	50
Results	IVI	Learning soft skills and awareness of the upcoming trends, Maintain Work Life Balance
	No. of Nodes	6
	No. of TN	4
	Depth	2

Source: Output generated from SPSS 21

Table 3 Gain summary for nodes

Node	N	Percent	Mean
2	130	18.6%	3.99
5	314	44.9%	3.54
1	90	12.9%	3.32
4	166	23.7%	2.93
Growing Method: CHAID Dependent Variable: Performance of the employees			

Source: Output generated from SPSS 21

The model summary using the CHAID (Chi- squared Automatic Interaction Detector) method identifies the relationship between employability skills and the actual performance of employees in the health care sector, focusing on psychological skills. Among the independent variables, learning soft skills and awareness of upcoming trends and Maintaining work-

life balance emerged as the most significant predictors of performance. The model produced 6 nodes, including 4 terminal nodes, with a maximum depth of 2, indicating a relatively simple and interpretable decision tree. The inclusion of only two key predictors suggests that these psychological skill-related factors have a stronger direct influence on employee performance than other measured skills. This highlights the critical role of continuous learning and personal well-being management in enhancing effectiveness in the health care sector. The absence of a validation sample means the model's predictive accuracy should be interpreted with caution, but the results still provide valuable insights for targeted training and policy development.

FINDINGS AND SUGGESTIONS

The study found that psychological skills form a critical dimension of employability skills in the health care sector of Tamil Nadu. Factor analysis revealed two main clusters: the first included professionalism in diverse settings, discovering new opportunities, learning soft skills and staying aware of trends, conflict management, adaptability, maintaining work-life balance, and the ability to tackle assemblages; the second comprised loyalty and integrity along with accountability to superiors. Among these, loyalty and integrity emerged as the most influential psychological skill factor affecting performance. Tree analysis indicated that "learning soft skills and awareness of upcoming trends" and "maintaining work-life balance" were the most significant predictors of employee performance, highlighting their direct and substantial influence. Targeted training programs should be developed to strengthen both psychological and technical employability skills, with particular emphasis on loyalty, integrity, adaptability, and conflict management. Health care institutions should implement continuous learning initiatives to keep employees updated with emerging trends and soft skills. Structured work-life balance policies are essential to improve employee well-being and performance. Recruitment and appraisal systems should integrate psychological skill assessments alongside technical qualifications.

Collaborative programs between academia and industry can help align educational outcomes with real workplace needs, ensuring a sustainable and skilled workforce in the health care sector.

CONCLUSION

The study confirms that psychological skills are a pivotal component of employability in the health care sector of Tamil Nadu, with loyalty, integrity, continuous learning, and work-life balance emerging as the most influential factors driving employee performance. Factor analysis effectively identified two key skill clusters, while tree analysis emphasized the dominant role of learning soft skills, staying aware of trends, and maintaining personal well-being. These findings highlight that enhancing employee performance in health care requires a balanced approach that integrates technical expertise with strong psychological competencies.

By addressing skill gaps through targeted training, supportive policies, and industry- academia collaboration, health care institutions can build a more resilient, adaptable, and high-performing workforce capable of delivering quality patient care in an evolving health care environment.

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Reels, Reach, And Results: A Study of Instagram Algorithms and Creators' Marketing Strategies in Regional India

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ABSTRACT

This study investigates how Instagram's algorithmic structure influences content visibility, audience reach, and marketing outcomes for digital creators, with a specific focus on creators operating outside metropolitan regions. Using a mixed-methods approach that combines quantitative engagement metrics and qualitative interviews, the research explores the relationship between algorithmic changes and content performance. The study also examines how creators adapt their marketing strategies—including content timing, format, hashtag use, and audience targeting—to maintain visibility and monetization. Findings reveal that algorithmic updates significantly affect reach and engagement, especially for regional language content, and that creators with adaptive strategies fare better in maintaining audience retention and brand collaborations. The paper concludes by emphasizing the need for algorithmic transparency and platform support for regional creators, suggesting that equitable algorithmic practices can enhance the digital economy in emerging markets like Tamil Nadu and other parts of regional India.

KEYWORDS *: Instagram algorithms, Digital creators, Marketing outcomes.*

INTRODUCTION

The digital landscape has been profoundly transformed by the rise of social media, leading to significant shifts in advertising and marketing strategies [1]. Traditional advertising methods are increasingly being supplemented, and often supplanted, by innovative approaches that leverage the vast reach and interactive nature of social media platforms [2]. Among these, influencer marketing has emerged as a particularly potent force, characterized by collaborations between social media influencers and brands to craft effective promotional campaigns. This phenomenon is not merely a global trend but a rapidly expanding sector, especially within India, where over 90% of millennials actively engage with social media platforms. The Indian influencer marketing industry is projected to achieve a substantial valuation of 21 billion dollars by 2025, underscoring its pivotal role in the country's economic and digital future.

The Evolution of Influencer Marketing and its Impact

Influencer marketing thrives on the ability of individuals with creative content to captivate and engage large audiences [3]. Brands are increasingly recognizing the value of co- creating content with these influencers, often through sponsorships, to promote their products and services effectively on social media platforms. The core of an influencer's strategy involves targeting specific audiences, securing endorsements, and continuously refining and reviewing campaigns to measure their effectiveness and ensure a positive impact on consumers. This model represents a dynamic shift from one-way communication to an interactive customer-brand relationship, fostered through virtual engagement [4].

Consumers today are highly dependent on social media platforms for information and purchasing decisions [5]. While businesses face challenges and costs in promoting

themselves directly on these platforms, influencers, with their established networks and significant reach, offer a streamlined path to connect with the right target audience and disseminate content effectively.

The content produced by influencers is often perceived as professional and highly attractive, even when seemingly informal, drawing considerable attention and serving as a powerful and effective means to reach customers through various campaigns [6]. This effectiveness is rooted in the influencer's ability to provide in-depth information about the products they endorse, building credibility and trust with their followers. As consumers increasingly rely on digital content, influencers become invaluable partners for businesses striving to thrive in the social media landscape.

Understanding Reach and Engagement in Influencer Campaigns

Reach is a critical metric in influencer marketing, signifying the breadth of an audience an influencer can connect with. Endorsing products with multiple influencers, even those with similar follower counts, can significantly expand reach, promoting concepts to consumers with deeper insights into campaign effectiveness [7]. The global pervasive use of social media, with nearly 40% of the population influenced to purchase through social media content, highlights the imperative for businesses to partner with influencers to meet consumer expectations and drive growth.

Influencer campaigns are acknowledged for their immense potential to draw consumers from online platforms to offline stores, with data and feedback enabling analysis of influencer efficiency and engagement levels [8]. The joy and creativity an influencer brings to their content are key attractors for consumers, facilitating broad reach. Effective reach also involves understanding user data and timing campaigns to align with peak consumer activity to maximize awareness and impression [9].

Engagement

Refers to the interaction and connection influencers foster with their audience. This can involve creating content that is not only attractive and interactive but also resonates deeply with followers. Even micro-influencers, particularly those in rural areas, contribute significantly to engagement, often enhancing their content through post- production rather than relying solely on raw footage to create a special impression. This meticulous approach to content creation and audience interaction ultimately translates into effective business promotion. The CARE model (Content & Campaign, Awareness, Reach & Review, and Engagement) provides a framework for analyzing influencer marketing activities, emphasizing these key identifiers [10].

The Regional Indian Context and Future Research

Given the specific focus on 'Regional India,' this study aims to delve into how Instagram algorithms influence the marketing strategies of creators in diverse regional contexts. While the provided contexts broadly discuss influencer marketing, they highlight the general trends and the significant growth of this sector within India. The unique characteristics of regional audiences, local cultural nuances, and the specific ways Instagram's algorithmic changes impact content visibility and creator strategies in these areas warrant detailed investigation. This research will explore how creators adapt their 'Reels' content, optimize for 'Reach,' and measure 'Results' within the distinct digital ecosystem of regional India, contributing to a more nuanced understanding of localized digital marketing practices [11].

REVIEW OF LITERATURE

Innovatively, Liang and Wolfe (2022) focus their study on exploring the effects of different posting formats within the niche context of Instagram Reels, reflecting contemporary interest in short-form video content dynamics on social media platforms. Employing an experimental design, they systematically investigate the impact of posting format variations on online engagement metrics, offering valuable insights for content creators and marketers. However, potential limitations include the study's limited generalizability to other populations or contexts, its focus on immediate online engagement metrics without considering longer-term effects, and the specificity of findings to Instagram Reels, which may not extend to other platforms or content formats [12].

Putri and Windasari likely focus on Instagram-based

social media marketing strategies for the fashion industry, highlighting creative content creation, influencer collaborations, and data-driven recommendations to boost brand visibility and sales, while noting limitations from single case reliance and platform dependency [13].

A social media platform is a website or app that enables users to create and share content. It allows interaction with others globally through profiles and posts. Users can access it via smartphones, tablets, or computers. Content sharing is subject to the platform's permissions. Overall, it fosters communication, engagement, and connection [14].

Perceived ease of use denotes the degree to which an individual believes that utilizing a technology will involve minimal effort. Among small business owners in Pakistan, this perception plays a crucial role in shaping their willingness to adopt Instagram Reels as a marketing tool. Factors such as a user- friendly interface, the simplicity of creating and editing Reels, and the accessibility of tutorials or learning resources can substantially enhance perceived ease of use.

Together, these factors shape their decision to integrate this feature into their promotional strategies [15].

There is a gap in research on the everyday negotiation strategies of social media influencers in the global South, particularly in how they navigate platform features and engagement templates to establish a niche for self-expression. This involves positioning themselves as global content creators who maintain relevance across cultural and national boundaries, highlighting the advertising potential of the influencer economy [16].

The functions, features, and interface elements of digital platforms shape the scope of their technological affordances. However, scholars [17], [18], [19] contend that the ways in which social media platforms are (re) used cannot be predetermined. When influencers create and share content, they do not treat these affordances as fixed, inherent functions that dictate the boundaries of technological, cultural, interpersonal, or community interactions online. Rather, they understand social media affordances as "ongoing enactments by specific users that vary across space and time" [19].

Regional content creators often encounter challenges such as language barriers and limited access to resources, which can restrict their reach on digital platforms [20]. Expanding on this, Tamil content creators, in particular, face additional difficulties in gaining visibility because of algorithmic bias, which tends to favor mainstream or widely spoken languages over regional ones, further limiting their audience growth and recognition [21].

STATEMENT OF THE PROBLEM

In the digital age, social media platforms like Instagram have become essential for content creators to reach audiences, promote brands, and build careers. However, the visibility and success of digital content are increasingly influenced by complex algorithmic systems that prioritize certain content based on engagement metrics, format, and platform trends. While this environment may benefit well-resourced creators in urban areas, it presents significant challenges for digital creators in regional parts of India, such as Tamil Nadu. Regional creators often lack access to platform training, marketing tools, and algorithmic knowledge. Language barriers, cultural nuances, and inconsistent content visibility further widen the gap between metropolitan and regional influencers. Although Instagram Reels has opened up new opportunities, many creators from non-metropolitan areas find it difficult to achieve consistent engagement due to algorithmic opacity and unequal platform support. Moreover, there is limited academic research specifically addressing how regional Indian creators adapt their marketing strategies in response to Instagram's algorithmic changes. The absence of transparency in content ranking systems raises concerns about fairness, digital inclusion, and equitable representation. This study aims to address this gap by exploring the impact of Instagram algorithms on the marketing outcomes of regional digital creators, with a specific focus on their challenges, strategies, and the implications for the broader creator economy

OBJECTIVES OF THE STUDY

1. To examine how Instagram's algorithm affects the visibility and engagement of content created by regional digital creators in India.
2. To analyze the marketing strategies adopted by regional creators, particularly in Tamil Nadu, to adapt to algorithmic changes on Instagram.
3. To investigate the challenges faced by regional

influencers in accessing brand collaborations and monetization opportunities.

METHODOLOGY

Methodology plays a vital role in establishing a logical and scientific base for any research study. It ensures reliability, validity, and meaningful interpretation of findings by clearly outlining how variables are studied and analyzed. In this context, the research methodology serves as the foundational structure of the present investigation.

Geographical Area of the Study: The study is confined to Tamil Nadu, with a particular focus on regional districts like Thanjavur. This region was selected due to its rising population of digital content creators using Instagram Reels. It represents a blend of cultural diversity, regional language users, and digital entrepreneurial growth.

Population and Sampling: The population comprises digital creators from Tamil Nadu who actively use Instagram Reels for content creation and marketing. A multi-stage sampling technique was used to select the sample.

First Stage: 14 districts with strong regional creator activity were identified.

Second Stage: 22 town panchayats with high Instagram engagement were selected from these districts.

Third Stage: 100 village and semi-urban panchayats were chosen to reflect regional diversity.

From these areas, 500 digital content creators were selected using purposive sampling based on the following criteria:

- Active use of Instagram Reels
- Use of Tamil or other regional language content
- Demonstrated audience engagement
- Participation in branding or monetization activities

This method ensured inclusion of both small and medium-scale creators operating within regional content ecosystems.

Sources and Collection of Data: The study relied on both primary and secondary data:

- Primary Data: Collected through structured questionnaires and semi- structured interviews conducted with the selected digital creators. Quantitative metrics such as views, likes, shares, and follower growth were also gathered.
- Secondary Data: Sourced from academic journals, published reports, online media publications, and Instagram's official help resources related to algorithms and platform trends.

Presentation and Analysis of Data: Data was organized and presented using tables, charts, and graphs.

- Quantitative data was analyzed using statistical tools such as percentages, averages, and correlation techniques to evaluate the relationship between content features and engagement outcomes.
- Qualitative data from interviews was thematically analyzed to extract patterns regarding algorithmic awareness, strategy adaptation, and platform challenges.

Rating the Attitude of Respondents: A five- point Likert scale was used to assess creators' attitudes towards Instagram algorithms, content strategy, platform fairness, and monetization opportunities. Ratings ranged from:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

This helped measure the degree of agreement and satisfaction of the respondents regarding various aspects of their digital journey.

Ethical Considerations: All participants provided informed consent. Their identities and social media information were kept confidential and used strictly for academic purposes. The study adhered to ethical guidelines in data handling and reporting.

ANALYSIS AND FINDINGS

The overall attitude score was calculated as an aggregate mean of all four dimensions studied. This provides a composite view of creators' sentiment toward

Instagram's platform ecosystem. The aggregate mean score of 3.42 indicates that creators generally hold a moderately positive view of Instagram, acknowledging the platform's potential while also being aware of its limitations.

Table 1 Overall Attitude Score of Digital Creators Toward Instagram's Platform Ecosystem

Overall Attitude Dimension	Aggregate Mean	Aggregate Standard Deviation	Coefficient of Variation (%)	Interpretation
Combined Attitude Score	3.42	0.91	26.61	Moderately positive but variable response

Source: Output generated from SPSS 22

The standard deviation of 0.91 reflects notable variability in perceptions, suggesting that creators' experiences with Instagram differ widely based on factors such as their follower base, geographical location, content niche, and understanding of how algorithms work. The coefficient of variation, calculated at 26.61%, further points to a moderate level of inconsistency in responses, highlighting that individual circumstances significantly shape attitudes toward the platform. Overall, the analysis reveals that while creators see Instagram Reels as an avenue for growth and audience engagement, they remain cautious due to concerns over content visibility, perceived fairness of algorithms, and the limited monetization opportunities available. This result shows a balanced yet cautious sentiment toward Instagram. A mean above the neutral midpoint suggests that creators do find value in the platform, especially its ability to reach audiences through Reels. However, the relatively high standard deviation and moderate coefficient of variation highlight that this optimism is not uniform, some creators benefit significantly from the platform, while others face persistent challenges. This disparity can be traced to differences in access to resources, understanding of platform tools, and the influence of algorithmic preferences. In practical terms, the findings underline that Instagram's appeal is tempered by structural and operational concerns, meaning that platform improvements in fairness, visibility, and monetization could lead to a more uniformly positive creator experience.

Standard Deviation and Coefficient of Variation

The analysis of standard deviation and coefficient of variation helps to understand not just the average attitudes of respondents, but also the consistency of their opinions. While some factors showed strong agreement and shared perceptions among creators, others revealed wide differences in experience and viewpoint. Lower variation indicates a stable consensus, often seen in areas where creators have similar experiences. Higher variation points to divided opinions, typically linked to personal circumstances such as audience size, language, or niche. This comparison highlights which factors are universally acknowledged and which remain contested within the creator community. The following findings emerged from the analysis of the respondents' attitudes:

Table 2 Respondents' Attitudes Toward Key Factors Influencing Instagram Content Creation

Factor	Mean Score	Standard Deviation	Coefficient of Variation (%)	Interpretation
Instagram Algorithms	3.97	0.88	22.17	High influence on content reach
Content Strategy	4.12	0.79	19.17	Strong positive effect on engagement
Platform Fairness	2.68	1.02	38.06	Mixed views; concern over algorithmic bias
Monetization Opportunities	2.91	0.94	32.30	Moderate dissatisfaction; limited opportunities

Source: Output generated from SPSS 22

The analysis of respondents' attitudes toward key factors influencing Instagram content creation reveals a nuanced perspective on how creators perceive the platform. Instagram algorithms received a mean score of 3.97 with a relatively low coefficient of

variation (22.17%), indicating a broad consensus that algorithms have a strong influence on content reach. This is supported by the fact that 68% of respondents agreed or strongly agreed that algorithmic behavior significantly impacts visibility. Content strategy scored the highest mean (4.12) and had the lowest variation (19.17%), suggesting that creators widely recognize the importance of aligning with trends, posting consistently, and using effective formats—an opinion echoed by the 74% who reported improved visibility through strategic content planning.

In contrast, platform fairness scored much lower (mean = 2.68) and showed the highest variability (38.06%), indicating divided opinions, with only 39% of respondents believing that Instagram's algorithm treats all creators equally—especially concerning regional language users who feel disadvantaged by linguistic bias. Monetization opportunities also received a low mean score (2.91) and high variation (32.30%), reflecting moderate dissatisfaction; 58% of creators expressed frustration with limited earning avenues despite significant effort invested in content creation.

Qualitative feedback reinforced these findings, highlighting recurring frustrations over reach inconsistency, perceived algorithmic bias against non-mainstream languages, and the unpredictability caused by frequent algorithm updates. Overall, while creators acknowledge that mastering content strategy and understanding algorithms can boost performance, their optimism is dampened by concerns over fairness, inclusivity, and inadequate financial incentives. This suggests that any improvement in platform transparency, equitable treatment, and monetization support could greatly enhance creator satisfaction and engagement.

Table 3 Tree Structured Analysis – Factors Influencing Social Media Influencer Success

Node	Description	N	Mean	% of Sample
0	All respondents	150	4.05	100%
1	High Cross-Cultural Relevance (Score ≥ 4.2)	78	4.38	52.0%
2	Low Cross-Cultural Relevance (Score < 4.2)	72	3.70	48.0%
3	Within Node 1: High Platform Affordances (≥ 4.1)	50	4.52	33.3%
4	Within Node 1: Low Platform Affordances (< 4.1)	28	4.15	18.7%
5	Within Node 2: High Self-Expression Opportunities (≥ 4.0)	40	3.85	26.7%
6	Within Node 2: Low Self-Expression Opportunities (< 4.0)	32	3.48	21.3%

Growing Method: CHAID

Dependent Variable: Influencer Success Score Source: Output generated from SPSS 21

The CHAID tree analysis shows that cross- cultural relevance is the strongest differentiator of influencer success. Influencers with high cross-cultural relevance (Node 1) achieve higher success scores (Mean = 4.38) compared to those with lower relevance (Node 2, Mean = 3.70). Within the high relevance group, platform affordances further boost success, with those scoring high on this factor (Node 3, Mean = 4.52) achieving the highest overall performance. Conversely, in the low relevance group, self- expression opportunities play a key role, with higher self-expression leading to moderately better outcomes (Node 5, Mean = 3.85). This suggests that for influencers in the global South, cross-cultural engagement combined with effective use of platform tools is critical for achieving and sustaining success.

SUGGESTIONS

Based on the key findings of this study, several practical suggestions are offered to improve the experience and outcomes of regional Instagram content creators. First and foremost, Instagram must make its algorithmic functioning more transparent.

Many creators expressed uncertainty about how their content is ranked, leading to confusion and inconsistent engagement. By clarifying the logic behind content distribution, the platform can empower creators to better align with algorithmic preferences. The platform must prioritize visibility for regional language content, especially Tamil. Creators using regional languages often face reduced reach, limiting their growth. A

multilingual-friendly algorithm is essential to ensure fairness and linguistic diversity on Instagram. The study recommends expanding monetization features like Reels bonuses, paid partnerships, and in-app tipping to regional creators. Many participants reported barriers in accessing these tools. Ensuring equal access can help creators sustain their work. Educational support is crucial. Instagram should offer workshops, tutorials, and online resources to teach regional creators about best practices, trends, content analytics, and monetization techniques. Such programs would build confidence and technical know-how among emerging influencers. Instagram can play a more active role in fostering brand collaborations at the regional level. By curating lists of regional influencers for businesses, or offering brand-matching tools, the platform can boost local digital economies. Creators need better access to detailed analytics that reflect regional audience behavior. Customized insights would allow for data-driven strategies and improved decision-making. Community- building efforts like creator meetups, regional creator days, and workshops will help foster solidarity and shared learning. These events would amplify underrepresented voices and promote knowledge exchange among creators.

CONCLUSION

This study sheds light on the influence of Instagram algorithms on the marketing strategies and engagement outcomes of regional content creators in Tamil Nadu. It reveals that while Instagram Reels provide substantial opportunities for visibility and growth, the algorithmic system poses challenges for creators working in regional languages. The findings emphasize the importance of platform transparency, equitable monetization opportunities, and tailored educational support. Regional creators possess immense potential but require targeted support to overcome algorithmic bias and visibility barriers. If Instagram and similar platforms prioritize inclusivity, language diversity, and regional representation, the digital creator economy can flourish more equitably. This research ultimately highlights the need for a more transparent, supportive, and accessible social media environment that empowers all creators, regardless of their linguistic or geographic background.

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